No. 2.00

Accelerator Test Facility
Safety Assessment Document
Building 820

Approvals

11/9/04
Michael J. Zarcone, Preparer, Physics Dept. ES&H Coordinator — Date

11/12/04
Vitaly Yakimenko, ATF Head — Date

11/18/04
Stephen M Shapiro for Physics Department ES&H Committee — Date

11/18/04
Samuel Aronson, Physics Department Chair — Date

11/22/04
Thomas Kirk, HENP Associate Lab Director — Date

1/11/05
Michael Bebon, Deputy Director of Operations — Date

Initial SAD 1989
Revised October 22, 1999
Revised October 1, 2004

ACCELERATOR TEST FACILITY SAFETY ASSESSMENT DOCUMENT

TABLE OF CONTENTS

Figures

Appendices

1. INTRODUCTION AND DESCRIPTION OF THE FACILITY

The Accelerator Test Facility (ATF) comprises a 120 MeV electron linear accelerator and an experimental area to study advanced acceleration techniques and to carry out research involving free electron lasers and basic electrodynamics. The linear accelerator is housed in the low bay area of Building 820 as shown in Figure 1 and an experimental area building adjacent to Building 820 shown in Figure 4. Prior to operation of the ATF a Safety Assessment Report was prepared in 1989 and approved by DOE. In 1999 the Safety Assessment Document (SAD) was revised and approved. This Safety Assessment Document is a revision of the 1999 document and reflects recent organizational changes of the ATF into the Physics Department as well as referring to more recent ES&H Subject Areas and Standards. It is in compliance with DOE Order 420.2.

1.1 Description of the Facility

The general arrangement of the building shown in Figure 1 provides for an electron gun with a laser excited photocathode, a low energy (– 5 MeV) beam transport and beam analysis system, two traveling wave linear accelerator sections and a high energy (120 MeV) beam transport and beam shaping system to provide beam appropriate for the experimental program. The experimental area shown in Figure 4 also houses two of the lasers for experimental purposes. The experimental hall contains three separate beam lines for experimental purposes.

The schematic diagram (Figure 2) shows the system, which is designed for the study of advanced accelerator techniques. The photocathode of the r.f. electron gun is illuminated by a 10psec laser pulse, one to three times per second, at a laser frequency close to the photoemission threshold (λ –0.25μm) in order to minimize the transverse emittance. The very high radio frequency electric field strength (–100 MV/m) at the cathode allows us to maintain a very low emittance (– 10^{-8} rad-m for a bunch charge of 3×10^9 electrons) at the 120 MeV output energy from the linear accelerator. The gun laser gates a high power CO_2 laser, which, together with amplifiers to boost the pulsed output power level to 1 terawatt, may be used to excite a plasma to produce a very high accelerating field. The interaction space of the low emittance electron beam with the laser field is approximately 3 mm long and 100 μm in diameter. The light pulses of the two lasers are synchronized with the 2856 MHz r.f. for the electron gun and the accelerating section.

The output energy and spread of the output beam from this experiment is measured in a special spectrometer situated immediately downstream of the plasma accelerator. All of the equipment is carefully supported to minimize the effects of mechanical vibrations. A Life Safety Analysis of the ATF is given in Section 3.3 of this SAD and full descriptions of the laser systems including laser interlocks and search procedures are contained in the Procedures for the Accelerator Test Facility.

1.2 Worker and Public Safety

In order to protect both workers and the general public, the accelerator and experimental systems are housed in a fully shielded and secured area with appropriate audible and visual signs. There are no exposed electrical systems at voltages greater than 24V except for the 90° Magnet Power Supply which is set to <50Vdc output, and there is no release of radiation or toxic materials that can cause harm to workers or the general public. The high power lasers utilized are also contained in dually interlocked areas requiring key access and are not accessible to the general public. The electron beam is not a source of contamination. There are no routinely generated radiological disposables. However, some quantities of activated copper, aluminum and stainless steel shall be disposed of as part of a decommissioning plan. The total volume of such disposables would be <10 cubic feet.

2. SUMMARY/CONCLUSIONS

The shielding design together with the radiation security interlock search and secure procedures ensure that no personnel are exposed to any levels of radiation that would exceed the BNL untrained, unescorted personnel limit of 25 mrem/yr due to the operation of the Accelerator Test Facility at the maximum permitted operation levels given in Section 4.5.2.2.2 of this SAD in the case of a maximum credible accident.

Design and construction of electrical equipment ensures that no exposed high voltages are present anywhere in the facility. High voltage enclosures are either locked or fully interlocked. Normal policy prohibits "working hot" on electrical equipment and any deviation from this requires a permit and working hot procedure. Personnel are trained in these policies and in Lock/Out Tag/Out procedures.

Non-hazardous fluids are used for cleaning purposes where possible and all chemical inventories are kept to a minimum. The ATF generates a minimum amount of hazardous waste. The building has been designed to conform with the National Fire Protection Association "Life Safety Code" No. 101 and DOE Order 420.1 Facility Safety 10/13/95.

The high power, pulsed, laser beams are contained in interlocked enclosures or rooms and are transported inside opaque beam tubes. Entry into interlocked laser areas requires the use of protective eyewear as defined in the laser SOPs.

The entire facility may be operated at its permitted operation levels with minimal risk to the safety and health of staff, users or the general public.

3. SITE FACILITY AND OPERATIONS DESCRIPTION

3.1 Site Location

3.1.1 Introduction

The BNL Accelerator Test Facility (ATF) has been evaluated as mandated in DOE Order 5480.25 "Safety of Accelerator Facilities," against the criteria of DOE Order 6430.1A "General Design Criteria" regarding wind, flood, and earthquake design criteria. DOE Order 5480.28 "A Natural Phenomena Hazards Mitigation" (NPH) and its associated standards were used as guidance for this evaluation. Details on site geography, seismology, meteorology, hydrology and demography are contained in "DOE Accelerator Order 5480.25 Implementation Plan for Brookhaven National Laboratory Natural Phenomena Hazards Evaluation" April 25, 1994 by Steve Hoey. It is the consensus of seismologists that no significant quakes are to be expected in the foreseeable future. The ATF Building is a pre-existing structure built in the early 1950's.

The ATF is considered Accelerator Safety Level Low Hazard Class and NPH Performance Class 2 as defined in DOE Order 5480.28. It does not contain significant quantities of radioactive or chemical materials. Should the NPH event cause significant damage the impact would be mission related and not present a hazard to the public.

An Accelerator Readiness Review (ARR) was performed prior to the operation of the Accelerator Test Facility in 1989.

3.1.2 Accelerator Test Facility Location

The ATF is a user facility for accelerator and beam physics. It is operated by the Physics Department and the Center of Accelerator Physics (CAP) to study advanced acceleration techniques and to carry out research involving free electron lasers and basic electrodynamics. This facility makes use of a 120 MeV electron linear accelerator utilizing a radio frequency electron gun excited by a semiconductor laser giving very short photon microbunches to provide a very bright source of electrons with total charge of 1 nanocoulomb per microbunch. The ATF is under the administrative control of the Physics Department. The ATF is housed in the west side of Building 820 consisting of a steel exterior and frame, housing a single story with a high-bay area.

3.2. Accelerator Systems Design

3.2.1 Introduction

The linear accelerator (Figures 1 and 2) comprises an electron gun, a low energy beam transport system, two traveling wave accelerator sections and a high energy beam transport and beam shaping system. The klystron amplifiers and cooling systems are situated in the low bay area adjacent to the accelerator components, while the klystron modulator and other power supplies and controls for the beam transport and beam monitoring equipment are situated on a mezzanine above the accelerator. The accelerator and transport system is enclosed in a combination of lead and concrete, or borated polyethylene, shield of sufficient thickness to allow normal occupancy of the adjacent areas of Building 820. Shielded beam stops are provided for both electron gun and total linac operation in the accelerator tunnel in Building 820. The fenced off area next to the electron gun, the experimental hall, the CO_2 laser room (C1, C2) and the optical diagnostic room (C3) are radiologically Controlled Areas but not Radiation Areas.

3.2.2 Design Criteria

All of the accelerator and beam line components have been designed to conform with applicable guides, codes and standards. There are no deviations from DOE current design criteria. Any non-commercial equipment supplied to the ATF is reviewed by the ATF chief electrical or mechanical engineer and the Physics Department's ES&H Committee as appropriate. The evaluation criteria are given in Section 2.06 of the ATF Handbook. A separate safety review of the Accelerator Test Facility mezzanine and jib crane has been carried out and is available in the Physics Department's Safety & Training Office.

Section 2.04 of the ATF Handbook gives guidelines to be used in the design of electrical equipment, which are within those given in BNL ES&H Standard 1.5.0 that conforms to applicable DOE standards.

The interlock system design and search procedures are given in the Procedures for the Accelerator Test Facility . These systems are fully reviewed by Physics Department and BNL committees prior to their implementation and are in compliance with ES&H Standard 1.5.3, "Interlocks".

Experimental Reviews are carried out by the Physics Department Experiment Review Coordinator and the ES&H Committee and are in compliance with the Subject Area, Work Planning and Control for Experiments and Operations.

3.3 Fire Hazard Analysis

3.3.1 Introduction

The purpose of this section is to evaluate the ATF fire protection in regard to compliance with DOE Order 420.1. A detailed "Life Safety Code Analysis" is contained in Appendix I and a Fire Assessment/Fire Analysis Report generated by the BNL fire protection personnel is given as Appendix II.

3.3.2 Summary

The Accelerator Test Facility is housed in the low bay area of Building 820 and in an experimental building attached to the north end of 820 (see Figures 1 and 4).

New building additions added for ATF use have been provided with smoke detection and sprinklers. A sprinkler main has been brought into the building from the street and automatic sprinkler protection is provided in the experimental building. The mezzanine which houses much of the ATF electrical equipment is located in the low bay area of Building 820 and it has been provided with automatic sprinkler protection.

The Fire Assessment/Fire Analysis Report recommendation for the installation of automatic sprinkler protection throughout the unprotected areas of 820 is beyond the scope of the Physics Department. However, the recommendation for the automatic sprinkler protection in Building 820 is being added to a proposed line item funded site-wide fire protection improvements project (Phase IV). This project would include the installation of sprinkler systems in the few remaining unprotected areas in Building 820 utilized for ATF operations.

3.3.3 Analysis

The overall occupancy classification of the ATF area of Building 820 for Life Safety Code (LSC) purpose is General Industrial. No high hazard operations are associated with the operation of the ATF in Building 820. The occupancy load is above 100 sq. ft./person and the doors provide adequate means of egress. Stairs comply with the requirements of NFPA 101 and egress paths are of the required width. Common paths of travel and dead-end corridors are within the maximum allowed. Travel distances to exits are also in compliance with LSC and all exits discharge directly to a public way.

Adequate emergency lighting is provided and the required means of egress are adequately marked.

The ATF area of Building 820 is protected with a combination of automatic sprinklers, fixed temperature/rate of rise heat detectors, smoke detectors and manual fire alarms. Alarms are arranged to annunciate; locally, at BNL Fire/Rescue Headquarters (Building 599), and at BNL Police Headquarters (Building 50)

3.4 Safety Organization

3.4.1 Introduction

From a management viewpoint, safety is represented at a high level at the ATF. One can see from the ATF organization chart (Figures. 3a & 3b) that the ATF Head has direct line responsibility for the ATF Safety Program, which is administered through the Physics Department. The existing Physics Department Safety Program serves as the umbrella for the ATF Safety Program. An Emergency Plan has been developed for the ATF together with training programs. The plan is Section 2.01 of the ATF Handbook and training details are given in Section 4.00

3.4.2 Safety Committee

The ATF program is administratively part of the Physics Department and as such is reviewed by the Physics Department's Environment, Safety and Health (ES&H) Committee for the operation of the accelerator and the experimental facilities. The Physics ES&H Committee consists of Physics ES&H and professional staff as well as members representing the DOE Brookhaven Area Office Facility Representative, the Environmental Compliance Representative, Facility Support, and Radiation Control. . Other Subject Matter experts are included as needed or required. Guidelines for the Physics ES&H Committee are listed in Physics Department ES&H Policy Responsibilities and Authorities. Guidelines for Beam Line Review are in Section 2.10 of the ATF Handbook.

3.4.3 Laboratory Environmental Safety and Health (ES&H) Committee

Whenever policy changes not covered by this document or requiring a new SAD are made by the Physics ES&H Committee they are brought to the Laboratory Environmental, Safety and Health Committee for their review and recommendation for approval by the Director's Office. The policies are not implemented until such a review has taken place and approval has been obtained. In addition to the BNL ES&H Committee Reviews, members of the ESH/Q Directorate act as advisors to the Department in any safety matters. The Physics Department's Safety and Training Office assists in the implementation of the Laboratory Safety Program and also assists in training Physics/ATF personnel in safety matters. Operational Readiness Reviews are conducted by a committee appointed by the ESH/Q Directorate prior to operation of the Facility or when there is a major change in equipment layout or operations, which require a further review of this and other documentation.

3.4.4 Safety Training

For many of the training areas such as respiratory training, safe crane operation, materials handling and radiation dosimeter usage, the training will be given through the normal regularly scheduled Environment, Safety and Health Services training programs. However, there are a number of topics related to the Accelerator Test Facility, which require separate training programs. Topics such as electrical and radiation safety, laser safety and radio frequency radiation safety require such special training. Written procedures for securing radiation areas and for the operation of high voltage equipment are provided and operations staff is trained to carry out these procedures. Laser training and procedures for securing laser areas also are provided for involved personnel. A local Safety Representative, appointed by the ATF Head, has direct responsibility for bringing safety issues to the Physics Department's ES&H Coordinator. Building 820 is included in the regular Physics Department's Tier I Safety Tour program that covers each non-office area at least once each quarter. ATF Training Programs and Requirements are given in Section 4.00 and Training course contents in Section 4.01 of the ATF Handbook. All users are required to take a variety of web-based General Employee Trainings as well as safety specific training dependent on the work they will be performing and receive an ATF site specific training. The Physics Department tracks this training for ATF employees while the RHIC / AGS User's Office tracks the training for ATF users.

3.5. Experimental Operations

3.5.1 Introduction

The experimental area is divided into two separate regions, the fully interlocked laser rooms and the radiologically controlled experimental hall within them. The arrangement is shown in Figure 4. Detailed layout and shielding studies have been made, as described in Section 4.5.2, and originally reviewed by the NSLS, the Physics Department, and BNL ES&H Committees. The radiologically controlled experimental hall can be entered via a dual interlocked door at the southwest corner of the experimental area or by the dual interlocked door from the FEL experiment room. A double entry door is provided for heavy equipment access to the experimental area and this is situated on the west side of the experimental area near the north end of the building. This door has dual interlocks and no hardware on the outside so it is only available for emergency egress or equipment installation during maintenance periods. Three or more separate experiments may be set up in the experimental area, though only one can operate at any given time. The experimental area is a secured and interlocked radiation area not occupied during beam operation.

The high power lasers used for experimental research are housed, and transported between, the interlocked laser areas that are under controlled access as described in Section 4.5.3.2 of this report and in the Procedures for the Accelerator Test Facility. These areas are shielded from the experimental beam lines so that they may be occupied while the linear accelerator and experimental program are in full operational modes. There are three entry points to the laser areas, one through the door located on the east side, through a vestibule, one through the south door to the High Bay, and one through the south door of the experimental hall leading to the main control room. The dual interlocked personnel access door between the experimental hall and the FEL room is also used as an emergency exit from the FEL room. There are four independent laser rooms. They house the CO_2 lasers and the terawatt amplifier, both of which provide optical radiation for acceleration of electrons in experiments set up in the experimental area, and include the FEL experimental room which is used to analyze the light produced by the various FEL experiments, and the experimental hall itself. The experimental hall is a laser-controlled area that may be secured for laser and/or radiation. The FEL experiments may produce laser hazards from Class 2-4, while the facility lasers are strictly Class IV. Laser interlocks for the experimental hall are a separate and independent system except for the shared laser & radiation emergency stop buttons.

3.5.2 Experimental Area Operation Modes

Experiments are set up in one of the three beam lines shown in Figure 4. The beam line which first bends to the right after entering the experimental area is a relatively low current beam line operating at less than 10^8 electrons per second and ordinarily poses a relatively low radiation hazard. The other two beam lines are utilized for high current experiments ($\geq 10^{10}$ electrons/second) and therefore pose more serious radiation hazards. However some experiments carried out on this beam line require a momentum analysis system that may require bending the beam towards the exit door labyrinth. This can give rise to gamma rays being produced by off energy electrons striking the beam pipe upstream of the shielded beam stop. All experiments (or modifications to experiments) are reviewed by the Physics Department's ES&H Committee and must be approved. In addition, each experiment (or modification of an experiment) may require a radiation survey carried out by a Radiological Control Division representative and ATF Operator as determined by the ES&H Committee. The survey includes fault conditions. If an experiment does not satisfy safe operating conditions at the complete perimeter of the Experiment Hall it is not allowed to run. Shielding calculations must be carried out, and appropriate shielding provided, to ensure that radiation levels outside of the shielded area are in compliance with BNL standards. Experimental reviews and approvals are in compliance with the BNL Subject Area, Work Planning and Control for Experiments and Operations.

3.5.3 Radiation Hazards

In 4.5.2 we have estimated that 5×10^{19} electron MeV per month will be delivered to the beam stops situated at the north end of the experimental area. This will give rise to copious numbers of bremsstrahlung from electrons stopped in the beam stops and thence photoneutrons requiring concrete shielding. Fault conditions cause the electrons to be lost at other places in the beam transport lines, particularly where bending occurs, so it is necessary to shield the beam lines as well as the beam stops in the experimental area. Lead collars situated at intervals along the beam line are used to stop electrons thus lost and the beam line area is enclosed in a 4 ft. thick concrete enclosure for neutron shielding similar to that used for shielding the linear accelerator sections as shown in Figure 6. Extra concrete shielding up to 6 ft. total thickness is provided for the beam stops. The concrete shield for the north side of the building is placed outside in order to minimize the floor area occupied by shielding. A 1.5-foot thick roof covers the entire experimental area up to the beam stops. Extra concrete shields are also placed above the experimental beam lines as required. During early beam tests and commissioning, area radiation monitors were provided near each operating beam line to monitor fault conditions. Remote readout radiation monitors are located at sites where accidental beam losses may occur and machine operators are trained and have written instructions on the actions required if unusual radiation levels are experienced and alarms are sounded. Area monitors have been placed where dose levels are greatest and where verification of dose is needed. These monitors have been recording dose since 1995 as shown in Figure 8. Figure 4 shows the typical plan layout of shielding in the Experimental Area. Section 4.5.2.2 gives details of the shielding provided for this area.

3.5.4 Electrical Safety

The electrical distribution systems for the Experimental Area and the Laser Equipment Room are similar to that described in Section 3.6.4 and conform to the same codes and conditions. Door interlocks and grounding sticks are provided as necessary.

3.6 Operations Process

3.6.1 Introduction

Summary Table:

	Normal	Maximum
Output Beam Energy	75 MeV	120 MeV
Pulse Repetition Frequency	1.5 Hz	6 Hz
Radio-frequency Pulse Length	3.5 μS	3.5μS
Beam Pulse length (nominal)	10 pS	10 pS
Beam charge in one pulse	0.5 nC	* 1 nC
No. of beam pulses / macropulse	1 to 10	100

* The maximum charge of 1nC may not be practical for 100 bunch operation since it will, in general, cause beam loading in the electron gun that would change the beam energy and could cause the beam to be lost in the gun region and not be accelerated through the accelerating sections. In fact, for a charge of 1nC per beam bunch there could be a change in gun voltage of more than 6.5% during the duration of the 100 beam bunches and it is unlikely that this mode of operation at this level of charge would be useful for any of the planned experiments. At the present time the best operation, in multi-bunch mode has been with about 10 bunches with 0.5 nC or less per bunch.

The accelerator system has a number of different operating modes but for the purposes of this document we will concern ourselves with the mode giving rise to the most serious radiation hazard. In this mode the electron gun is operated in a multi-pulse laser mode and includes "dark current" electrons, where the beam pulse length is essentially equal to the radio frequency pulse length of up to 3.5 μsec which is the maximum attainable from the hardware utilized in the modulator and klystron tank. Note that, due to the high radio frequency field gradients present in the electron gun, field emission occurs which gives rise to what are called "dark current" electrons. These are accelerated in all directions by the strong electric fields present in the gun and thus produce intense x-rays around the electron gun. If the accelerator sections are misphased with respect to the electron gun, or each other, most of the electrons accelerated from the cathode are lost at energies between 5 MeV and 120 MeV over the whole length of the linac accelerator section and/or the beam transport system. It is also possible to mis-steer the 5 MeV input beam so that essentially a point source at the 5 MeV energy impacts the collimator just before the entrance to the first accelerating section. The radiofrequency gun will accelerate these "dark current" electrons to ≈5 MeV for essentially 180° of each rf cycle and will operate at up to a maximum attainable rate of 6 pulses per second. This can, under some operating conditions, give up to 10^{12} electrons per second from the gun at an energy of 5 MeV and an energy spread of up to 500 keV. A large number, of the order 90%, of these "dark current" electrons will normally be lost in the transport system situated just upstream of the accelerating sections. Others will be lost due to the rf capture process so only 10^{11} electrons per second will be available for acceleration through the two nominally 50 MeV accelerating sections. During low energy operation the electron gun is operated on its own with the beam being stopped in the collimator, which can also be used as a beam stop. A maximum power of 10 MW is available for gun operation. At this maximum power level output energy of up to 7 MeV is possible, assuming that the gun cavity is able to withstand the voltage obtained at this power level. The gun shielding and slit shielding are designed for this eventuality.

Normally the gun is operated with a photocathode where the beam microstructure is better defined and in this mode of operation the beam losses are lower by one to two orders of magnitude over the above situation. However, with the maximum available 100 microbunches each with a charge of 1 nC, there would be 6×10^{11} electrons per macropulse or a total of 3.6×10^{12} electrons per second for operation at the maximum available repetition rate of 6 Hz. These photoelectrons can also be stopped at the low energy collimator so we have conservatively designed the shielding there for 10^{13} electrons per second at a maximum energy of 7 MeV.

Most of the time the high-energy beam will be utilized for experiments carried out in one of the three available beam lines in the Experimental Area. The beam will be stopped after the Experimental Region in one of the fully shielded beam stops located at the end of the beam line in use. For tune up purposes and testing of accelerator components such as beam diagnostic equipment the beam may be stopped in a beam stop at the end of the straight ahead line housed in the shielded area of the Linac (see Figure 5). This is provided with the equivalent lead and concrete (and/or borated polyethylene) shielding as the beam stops at the end of the beam lines in the experimental area. A second fully shielded beam stop, after a bending magnet and defining slit in the line directed towards the Experimental Area, is used for tune-up purposes. It is possible to set up equipment in the Experimental Area and Experimental Laser Area while operating in these two modes.

3.6.2 Controlled Entry to the Experimental Hall

Entry to the experimental area hall is via two doors, one at the south and one through the laser areas FEL room at the north end of Building 820. Radiation protection interlocks are provided so that a doubly interlocked electron beam stop, situated in Building 820 in the transport line, near the junction of the linac tunnel Building 820 and the experimental building, is secured in place before entry to the shielded region of the experimental area is allowed. There are common optical paths for the laser light utilized to excite the photocathode in the case of high and low current operation. The low current path includes fixed optical attenuators to limit the optical power so that operation at high current, which could damage the experimental grating, is not possible. The experimental laser area is separately interlocked and shielded from the experimental beam lines with a door from it to the experimental area having the same interlock provisions as the other door to this area. A double door, situated at the northwest corner of the experimental building that is normally for egress only during non-beam operation allows forklift access to the experimental building for the delivery of large equipment. This door is also dual electrically interlocked. A movable shielded plug door provided for neutron shielding made up of borated polyethylene blocks and situated inside the double entry doors is moved into position and secured in place before a search of the area and operations can commence. Securing this plug door is included in the search and secure procedure given in Section 4.5.3.1.2 of this document and is also described in the Procedure for Operation of the ATF.

The ATF laser equipment area security interlock system, which allows controlled entry into the laser area rooms, while both the electron and Class IIIb or IV laser beams are in operation, is described in Section 4.5.3.2 of this document.

There are no special requirements with regard to general building entry since all radiation areas and laser operation areas are separately controlled.

3.6.3 Fire Hazard and Control

Building 820 is one of the older buildings on the BNL site; as such it does not contain a full building sprinkler system. Smoke and heat detectors are provided and there is an annunciator and signal system tied to the Site fire alarm system. Portable Halon 1211 fire extinguishers (UL rated 3A:80BC) are located throughout the ATF. The maximum travel distance to a fire extinguisher is 75 feet. Individual laboratories have their own fire extinguishers and smoke detection equipment.

The trailer, experimental area (experimental hall, terawatt & CO_2 laser rooms, FEL optical room - see Figure 4) and the equipment mezzanine in Building 820 are provided with automatic sprinkler protection. Smoke detection is provided in the experimental area, the mezzanine, the Control Room, the offices, the machine room and the YAG laser area. All other areas of the ATF are provided with heat detectors. Exiting for fire emergencies complies with the Life Safety Code NFPA101, 1994 (see Section 3.3 of this SAD).

The total value of the equipment located in the control room will not exceed $300,000.00 and all of it could be replaced within a six-month period. Backup magnetic tapes for the main operating system are stored in a metal file cabinet in another area of the building so the programmatic loss due to a fire would be minimal. Most of the high cost equipment in the ATF is directly associated with the accelerator itself, is made from copper, and is under a lead and concrete shield where it is protected from an external fire. The power equipment such as the modulator and power supplies for bending magnets, etc. are situated on the sprinklered mezzanine above the accelerators. The major cost items are the modulators and power supplies for the klystrons each of which cost $200,000.00. The two klystron amplifiers required for final operation were obtained from SLAC for shipping cost only and four replacement tubes are available. There is also approximately $200,000 of CAMAC equipment on the mezzanine. The CAMAC equipment could be replaced within six months.

Spares for the main components of these systems are available so they could be reconstructed over a 3 to 6 month period depending on the severity of any fire damage.

3.6.4 Electrical Safety Issues

The electrical power to operate the accelerator is distributed to the equipment at 208 or 480 volts, three phase, or 115 volts single phase, each with a separate ground connection. The installation of the distribution equipment is according to standard industrial practice for equipment of this type and conforms to applicable ANSI National Safety Codes and the National Electric Code. In order to prevent the electric shock hazard all control and instrumentation systems are well insulated, and operate at voltages less than 24 volts rms, the exception being the 90° Magnet Power

Supply which is set to <50Vdc output. They are within guidelines set forth in ANSI Spec. #39.5 (Electrical and Electrical Measuring and Controlling Instrument Safety Requirements) and DOE/EV-0051/1 (Electrical Safety Criteria for Research and Development Activities). Voltages above this 24 volt rms level for both AC power distribution as well as DC and AC equipment are either lock or interlock protected or behind bolted panels and covers according to the serviceability of the equipment. The klystron modulator system enclosures, which house high voltage equipment, have their entry doors electrically interlocked so that the high voltage is turned off when any of their doors are opened. In addition, grounding sticks are provided outside these enclosures to manually ground high voltage points within the enclosures prior to working on these systems. Unauthorized entry into the experimental hall will cause the Linac modulator to be turned off via a dual electrical interlock with this door and will cause a beam stop to be inserted in the high energy beam transport line. All the main circuit breakers for the power distribution system have lock out capability. The ATF Electrical Standards are given in Section 2.04 of the ATF Handbook.

3.6.5 Occupational Health Issues

3.6.5.1 Non-ionizing Radiation

The klystrons which provide the radio frequency power for the accelerator utilize a permanent magnet (5 gauss @ 1.4 meters) for beam focusing and provide high radio frequency power at an operating frequency of 2856 MHz . This power is transmitted from the klystrons to the accelerating sections and electron gun via vacuum waveguide.

3.6.5.2 Laser Issues

High power lasers (Class IV) are utilized to irradiate the cathode of the radio frequency electron gun and to accelerate electrons in the Experimental Hall. The laser beams are transported between rooms in enclosed pipes or inside interlocked enclosures for personnel protection.

3.7 Safety Design Procedures

3.7.1 Introduction

Worker safety is an integral part of the design process for the ATF equipment. Electrical, radiation (ionizing and non-ionizing) and general safety are considered and preventative measures such as interlocked enclosures with controlled entry and adequate shielding are provided.

3.7.2 Normal Building Access and Egress

Normal access to the buildings is from the north access road off Railroad Street. A large roll up door provides access to the high bay area of Building 820 and a forklift can be used to move equipment from the high bay to the low bay area. A platform off the existing mezzanine allows for transfer of light electrical equipment from a crane in the high bay area to the mezzanine. A small jib crane mounted on one of the vertical support columns for the high bay area allows the klystrons to be set in place. This crane installation has been reviewed by Plant Engineering and the ESH/Q Directorate (on file in the Physics Department's Safety & Training Office). There is also a jib crane in the Terawatt laser room. The jib cranes are inspected annually by PE and prior to each use by the operator as per ESH Standard 1.6.0 "Material Handling."

Personnel access to Building 820 is also available on the North, South and West walls of this building. Two stairways provide for personnel access to the mezzanine. Entrance to the experimental building is provided by a door on the east side from outside the building, through a vestibule into the laser equipment room area. There is also a personnel entry door with a vestibule through the west side into the experimental area. A double door situated on the west wall at the north end allows forklift access in order to place shielding blocks or large equipment.

Figure 1 shows the equipment layout in Building 820 and Figure 4 the experimental building. The floor plan and entries to the Experimental Building are shown there. In Building 820 an aisle is provided along the west side of the linear accelerator adjacent to the existing pump room and equipment rooms. Egress is also available through the control room on the west side of Building 820. Nowhere in the ATF complex is a person more than 60 feet from an exit.

3.7.3 Radiation Shielding and ALARA

In the process of designing the radiation shielding described in Section 4.5.2 ALARA concepts were utilized so that as far as workers at the Accelerator Test Facility are concerned there is minimal risk of exposure to ionizing radiation.

3.7.4 Occupational Health Hazards

Both the klystrons powering the linear accelerator and the lasers used for gun excitation and the experimental program pose potential occupational health hazards, which are considered in Section 4.3 of this document.

3.8 Worker Safety Controls

3.8.1 Introduction

Worker safety controls used at the Accelerator Test Facility include "fully" interlocked and controlled enclosures for radiation, laser and electrical safety as well as radiation monitoring and protective equipment.

3.8.2 Radiation Monitoring in the Experimental Halls, Laser Rooms, Linac Tunnel and Gun Area

Everyone working at the ATF in these areas is provided with a personal dosimeter that is collected and read monthly. In addition Area TLD's are located at appropriate locations around the facility, outside the shielded area. These are read and recorded on a regular basis and a database is maintained. Also a number of "CHIPMUNK" radiation monitors are used where accidental or unusual operations conditions could give rise to some radiation. They are read out and alarmed locally and in the Control Room.

3.8.3 Occupational Health Controls

The klystrons, which utilize permanent magnets developing fields of the order of 5 gauss at 1.4 meters, are situated in an elevated location not normally accessible to workers or the general public. Experiments may also make use of permanent magnets, as do the ion pumps for the beam lines. Warning signs are posted in the area of magnetic fields in compliance with the Static Magnetic Fields Subject Area and all workers in these areas receive Static Magnetic Field Training.

Safety goggles are provided for those workers who need to enter the interlocked laser areas in order to make adjustments while the lasers are operating. Eye examinations are required and only trained and authorized personnel may work in the laser areas.

4. SAFETY ANALYSIS

4.1 Radiation Safety Hazards

4.1.1 Prompt Radiation Hazards

Both the electron gun, when operated at its maximum energy, and the linear accelerator, are producers of copious numbers of bremsstrahlung. In addition, the "dark current" electrons also produce copious numbers of X-rays. Losses occur due to electron capture and/or equipment malfunction or missetting. The linear accelerator also gives rise to neutrons. Thus, we require both lead and concrete or borated polyethylene shielding to protect personnel from the radiation hazard. Normal electron losses will occur in the following locations and at the maximum energy and charge levels given below, for two modes of operation, i.e. for gun operation only and for full Linac operation.

4.1.1.1 Operating Electron Gun Only

Under certain operating conditions of the electron gun**,** up to 100 μA of peak current electrons are produced as "dark current" by field emission from all surfaces of the electron gun where high electric field gradients are present. Some fraction of these electrons are accelerated axially, in the forward direction up to the maximum energy of the electron gun (~ 7 MeV) for a fraction of each rf cycle during the 3 μsec rf pulse. They are also accelerated in the reverse direction, to lower than maximum energy (~ 3 MeV) during the reverse part of each rf cycle. These "dark current" electrons produce copious amounts of X-rays around the electron gun region and require lead shielding.

In addition, at 100 microbunch operation at 1nC per microbunch from a photocathode including "dark current" electrons, potential losses occur at the following locations:

1. At a collimator/faraday cup situated before the linear accelerator sections, $\approx 3.6 \times 10^{12}$ electrons per second of up to 7 MeV energy. This is essentially a point source.
2. Missetting of the transport line solenoid magnets or trim dipoles. This would give rise to a loss of beam over a line source downstream of the misset device which would result in an estimated electron loss of up to 2×10^{12} electrons per second over a length of ≈ 50 cm at an energy of up to 7 MeV.

4.1.1.2 Full Linac

Operation at up to 1 nanocoulomb per 100 microbunches in 6 macropulses per second can give rise to losses at the following locations.

1. The above potential loss modes are also included in this mode of operation.
2. During the capture process of electrons in the first accelerating section, electrons may be lost along the length of both accelerator sections and at the first bend magnet of the high energy beam transport system**;** 10^{12} electrons per second at energies between 7 MeV and 120 MeV.
3. In the high energy beam transport momentum selection system or after any mis-set focusing or bending magnet in this line, up to 10^{12} electrons per second of energies between 7 MeV and 120 MeV may be lost**.**
4. At profile monitors or beam stops in the transport line or experimental hall, 3.6×10^{12} electrons/sec at 120 MeV energy are stopped.
5. At the Linac beamstop.

Clearly the worst case conditions are at the low energy collimator or other point sources of loss in the low energy beam transport system, where 4.6×10^{12} electrons per second from both dark current and photo current electrons can be lost at an energy of 7 MeV, and in the high energy beam transport system where a point source loss of 10^{12} electrons per second of 120 MeV electrons are possible. All beam stops are provided with extra local shielding and therefore do not represent a worst case hazard.

4.1.1.2.1 Radiation Dose Rates From Gamma Radiation

4.1.1.2.1.1 Beam loss near a focusing quadrupole

In general terms the beam size is largest in one or other of the horizontal and vertical directions in the region of a quadrupole triplet. We will first consider a 1 % beam loss in the region of the first quadrupole triplet following the accelerating sections. (A similar situation will be present at subsequent quadrupole triplets). Electrons will only strike the beam pipe at an angle of less than 1 degree so they will pass through ~9.5cm of the 0.064inch thick, stainless steel, beam pipe. From Figure 1, we can see that, for normal setting of the quadrupole triplet, the beam size is largest just past the end of the third quadrupole of the triplet so that any electron losses will occur in that region. Assuming a density for stainless steel of 7.87 gm/cc we obtain an equivalent thickness of 74.77 gm/cm^2 . The average rate of energy loss <dE/dx> =11.8 MeV / gm/cm^2 so electrons hitting the wall at this angle would be stopped there. The range of 120MeV electrons in matter is ~ 80gm/cm^2 so the stopping distance in iron (or steel) is ~6.78 cm. Therefore, all of the electrons striking the beam pipe would produce gamma rays near the exit of the third quadrupole of the triplet. The gammas produced in the transverse direction will be somewhat shielded by the iron yoke of the quadrupole, or the steel flanges of the beam pipe. We may estimate the level of radiation at the point where these gammas would strike the yoke from a knowledge of the equivalent average current. The total average current in the electron beam, in multi-bunch mode, at a repetition frequency of 6 Hz, is 600nA and, assuming conservatively that 1% of this strikes the beam pipe, we obtain an equivalent current for the lost electrons of 6nA. (Note that for normal operation in single bunch mode at 6Hz the total average current in the beam is 6nA) We obtain the gamma emission rate at 90 degrees to the beam direction, in terms of absorbed dose index rate, at a reference distance of 1 m, from Appendix E of NCRP Report No. 51, as 5000 x I beam in mA or $3x10^{-3}$ rads m^2 /min. for 120 MeV electrons stopped in heavy or light elements. The yoke of the quadrupole is ~9.5 cm from the beam pipe and it is ~0.95cm thick. The rate at the yoke inner surface is 332 mrad/min, or 20 rad/hr. About 90% of this will pass through the steel yoke where it will be attenuated and eventually strike the concrete wall of the accelerator tunnel (the steel flanges of the beam pipe are thicker than the quadrupole yoke and will give better shielding). The nearest tunnel concrete wall on the control room side is ~ 0.3m from the gamma source and the radiation level at that point, after attenuation by the steel of the magnet yoke, is ~1.8 rad/hr. The 1.15m concrete wall will reduce this by a factor of $5x10^{-3}$ so that the level outside the concrete shield wall would be 9mrad/hr. On the high bay side the inner surface of the concrete wall is 0.5m from the source but the concrete wall there has an equivalent thickness of 1m. The level outside the wall there is calculated to be 13 mrad/hr. The inside surface of the tunnel roof is also 0.3m from the source and the concrete thickness is 1m so the level immediately outside the roof is 36 mrad/hr. The forward gammas which are more intense by about three orders of magnitude, and 90% of which are contained within an angle of 15 degrees, would travel some distance before hitting vacuum pipe flanges and the steel and or copper of subsequent beam line elements However, there is ample room to place a lead shield wall around the beam pipe at the nearest convenient location after the quadrupole triplet. A wall of lead extending 12 inches from the center of the beam line and 8 inches in length would provide sufficient shielding to reduce the radiation dose outside the shield wall to negligible levels. Beam losses at other quadrupole triplets along the H-line would result in the same levels of radiation. Note that there are no plans to operate the ATF at 6Hz and with 100 beam bunches of 1nC charge for any currently approved experiments. Operation has been conducted at ~ 10 beam bunches with <1nC charge per bunch at a repetition rate of 1.5 Hz. This would reduce the above rates by a factor of 40 (assuming the same 1% beam loss) giving manageable levels of <1 mrad/hr outside the shield wall. Operation for beam set up and studies at this maximum level would only be carried out, if at all, for an estimated 24 hours per year so, given the likely occupancy for a given region by any individual, the above levels are acceptable. The gamma rays striking the lead or concrete will produce photo neutrons and the shielding of these will be treated later in this document.

4.1.1.2.1.2 Loss near a dipole, bending magnet

There could be some electrons of energy lower than the design energy that make their way through the accelerating sections and up to the first dipole, bending magnet. These electrons would almost certainly be lost somewhere inside that magnet. We will assume that 1% of the beam is lost at some point inside the first dipole. Once again it is likely that the electrons will have energies close enough to those in the main beam that they will strike the beam pipe almost tangentially and give up all of their energy to it. The source level will be the same as for the quadrupole case but the dipole steel poles are much thicker and therefore provide more shielding in the transverse direction. The level outside the shield wall should be an order of magnitude less than for the quadrupole case and can be considered to be negligible in terms of radiation dose from gamma radiation. The more intense forward directed gamma beam will ultimately strike the floor of the tunnel and be absorbed there without contributing to the dose outside of the accelerator tunnel. Missetting of subsequent dipoles could also give rise to beam losses but this can be considered an accidental beam loss and will be considered in a later section of this document. The residual beam loss in the first dipole when a beam profile monitor is inserted into the beam is considered later.

4.1.1.2.1.3 Beam striking a profile monitor

During accelerating tuning or trouble shooting processes it is customary to introduce beam profile monitors into the electron beam in order to measure its position and size. These devices are typically made from a 0.25inch aluminum plate to the front surface of which is glued a coated glass plate, also 0.25 inches thick. These devices are set at an angle of 45 degrees to the direction of the electron beam and are viewed with a TV or CCD camera. They are not thick enough to stop the electron beam but will degrade the energy and also produce gamma rays. Electrons passing through these devices will continue along the beam line, albeit at lower energy, and will eventually strike the beam pipe at some location downstream thereby being stopped and producing more gamma rays. The range for 120 MeV electrons in glass or aluminum is 26.7 cm. So the electrons will readily pass through the profile monitor. The average energy loss of the electrons in passing through the 1.8 cm of glass and aluminum is 67 MeV (since $<dE/dx> = 13.7$ MeV/g/cm^2). So electrons with an energy of 53 MeV will continue down the beam line. Those hitting the profile monitor just upstream of the first quadrupole triplet will be over focused by it since they are at the wrong energy for proper focusing. Since there will be scattering of the electrons by the profile monitor the beam size will also be larger so some electrons will be lost inside the first triplet. Others will continue on down the beam line and into the first dipole bending magnet where they will be bent into the wall of the vacuum chamber and into the steel of the magnet poles where they will be stopped. The full 600nA beam hitting the profile monitor will produce only a fraction of the total number of gammas produced by stopping the electron beam, Most of the gammas will be produced when the beam is stopped inside the first dipole magnet.

If all of the 120 MeV electrons were stopped at the profile monitor the emission rate at 90 degrees would be 5000 x 600 x 10^{-6} rads m^2/min. If 53 MeV electrons were stopped the emission rate would be 4000 x 600 x 10^{-6} rads m^2/min. Therefore, 80% of the gammas produced by the electrons passing through the profile monitor are produced where the 55MeV beam is stopped.

We estimate that the 20% of the gammas that are produced at the profile monitor will give rise to an emission rate from aluminum at 90 degrees of 1000 x 600 x 10^{-6} rads m^2/min. or 0.6 rads m^2/ min. at 1m from the source. The radiation level at the inner surface of the tunnel wall on the high bay side that is 0.5m from the source will be 144 rads/hr. In passing through the 1m thick concrete wall this will be reduced by a factor of 15 x 10^{-3} to a level of 2.2 rads/hr. This level is unacceptable even for the short time, of the order of 1minute or less, that the individual profile monitor would be in place. A 4-inch thick lead wall around each profile monitor would reduce the level outside the shield wall by a factor of 100 or to 22 mrads/hr. The inner surface of the tunnel wall on the control room side is only 0.3m from the source but the concrete wall is 1.15m thick so the level outside the shield on that side, with 4 inches of lead shielding, will be 40 mrads/hr. The tunnel roof is 0.3m from the source and the concrete there is also 1.15m thick so the level just outside the roof is also 40 mrads/hr. Normally the ATF operates at 1.5 Hz and in single bunch mode where the average current is only 1.5nA. Under these conditions introduction of a profile monitor in the beam would result in negligible levels of ~ 100 μrads/hr outside the accelerator tunnel. A typical time for a given profile monitor to be in the beam is <1minute, so that, even when operating at the highest beam charge, the dose to a person right against the shield wall would be < 1mrad.

As stated earlier the bulk of the electron beam will be stopped in the steel of the dipole magnet and its beam chamber wall. The 53 MeV electrons will be bent downward directly into the chamber wall at a steep angle so they will pass through it and into the 1.5 inch thick steel pole piece. 53 MeV electrons are stopped by 4cm of steel so the remaining 1 cm will act as a partial shield for the gamma rays that are produced. For 53 MeV electrons stopped in steel the 90 degree emission rate at 1m is 4000 x (beam current in mA) rads m^2/min, or1.8 rads m^2/min. Gammas at 90 degrees from this source will see differing amounts of shielding material depending on the direction of travel. Those going downward will strike an aluminum support plate and then the floor of the accelerator tunnel. They will not contribute to gamma radiation levels outside of the tunnel. Those traveling upwards will strike the two walls of the vacuum chamber and then the 1.5 inch thick steel pole which is ~ 20 cm. from the source point. The tunnel roof is a further 30 cm. from the top of the magnet pole. Without taking account of the shielding provided by the steel magnet pole the level at the ceiling would be 9.6 rads/min or 576 rads/hr.1.5 inches of steel will reduce this to ~ 460 rads/hr. and the 1.15m concrete ceiling will reduce this to 4.7 rads/hr.

Six inches of lead above the dipole magnet gap region would reduce this to ~23 mrad/hr. This is an acceptable level since the time that any given monitor is in the beam is only a minute or less. In the two horizontal directions there is 4.5 inches of steel shielding adjacent to the source of gammas. This will attenuate the gammas by a factor of 10 directly opposite the point where the electron beam is stopped. The nearest wall, on the walkway side, is 30 cm from the source so the level at the inside surface there will be 160 rads/hr. the 1.15m thick wall will reduce this to 1.6 rads / hr. Four inches of lead will reduce this by a factor of 200 to a level of 8 mrad/hr. On the high bay side the tunnel wall is 60 cm from the source so the level there will be 40 rads/hr. The 1m thick concrete wall will reduce this to 600 mrad/hr and four inches of lead added will lower this to 0.7 mrad/hr. Forward directed gammas would strike the concrete floor of the accelerator tunnel and not contribute to radiation dose. The level of 23 mrem/hr. is rather high, even though it would only be present for short periods of time. However, our assumed maximum operating level for the average beam current is 40 times any presently planned operational situation and operation in that mode would only occur for 10% of the ATF operating time. It would be appropriate to introduce lead shielding if and when the ATF is set to operate at the maximum operating level and in the meantime to install a radiation monitor, with remote readout and an alarm, at the point where the maximum level of radiation could occur.

Alternatively, the accelerator could be operated at reduced repetition rate for set up and testing at the highest current level.

4.1.1.2.1.4 Beam Striking a profile monitor and the Faraday cup / beam stop situated after the third dipole of the chicane

During beam set up the fourth dipole of the chicane may be turned off to allow monitoring of the beam profile and charge in the straight ahead line after the third dipole of the chicane. The total number of hours for operation in this mode at the highest energy and with the highest total beam charge of 600nC will be very few maybe as little as 12 hours in a year. However, all of the beam charge will be stopped in the Faraday cup and we will calculate the gamma radiation production rate under this mode of operation. For a 120 MeV electron beam with a total current of 600 nA being stopped in an aluminum Faraday cup Appendix E of NCRP Report No.51 gives a gamma ray emission rate at zero degrees of 1800 rads m^2 / min. at a reference distance of 1m. The concrete roof of the tunnel is ~50 cm. From the source so the level there would be four times this rate or 7200 rads / min. (432000 rads/hr.) These forward gammas will strike the roof at an angle that will give rise to ~ 2.5 m of ordinary concrete shielding. This will reduce the radiation level by a factor of 100000 or to 4.32 rads/hr. 6 inches of lead shielding would reduce this by another factor of 500 to a level of 8.6 mrads/hr.

The emission rate at 90 degrees is 3.6 rads m^2 / min. at 1m. In this direction the roof is only ~ 20cm from the gamma source so the level at the roof is 30 rads/min or 1800 rads/hr. this would be reduced to 18 rads/hr. by the 1.15m thickness of concrete. Six inches of lead shielding would reduce this to 36mrads/hr. Remembering that the above maximum operational level is 40 times higher than any presently planned, and that even that mode of operation would be carried out for 10% or less of the ATF operating time, these levels are acceptable. Note also that operation of the ATF with beam being stopped in this particular Faraday cup would only occur during beam testing or set up which would be carried out for a short period of time. The likely dose to an individual situated at these locations would be less than 1mrem.

4.1.1.2.2 Radiation Dose From Neutrons

Wherever the gammas resulting from stopping electrons are attenuated in material neutrons are produced. In most cases we will be attenuating the gammas by the use of lead shielding and the shield will be the neutron source. In section 4.5.2.1 of the SAD for the ATF the neutron fluence at 2m from the beam stop in the Experimental Area where the full beam is stopped was calculated to be 4×10^{11} neutrons/cm^2 year. This assumed operation at the full energy, maximum repetition rate, and maximum beam current for the entire year. The worst situation in the accelerator tunnel region would be operation with the above beam conditions into the Faraday cup/beam stop situated after the third dipole in the chicane. However, operations at that location would only occur for at most 1% of the annual operating time so the flux at 2m would be 4×10^9 neutrons/cm^2 year. The concrete shielding of the tunnel roof is at the nearest point to the neutron source and is only 25cm from it. The flux in that region is therefore 2.6×10^{11} neutrons/cm^2 year.

To reduce this to 100mrem would require a reduction factor of 3.85×10^{-12} rem cm^2 to be applied to this fluence. This requires 240 g/cm^2 or 102 cm of ordinary concrete shielding. Operation at 1.5 Hz with 1nC charge in a single bunch for 200 hours per year into the Faraday cup/beam stop in the tunnel would give a neutron fluence of 6.4×10^{9} neutrons/cm^2 at 25cm from the source. This would require a reduction factor of 6.4×10^{-10} or 50 cm of ordinary concrete. The existing tunnel walls and roof are more than 1m thick and provide the necessary shielding for all anticipated operating conditions.

4.1.2 Activation Hazards

4.1.2.1 Air Activation

During normal operation, no air activation of any sort will occur since:

(a) The beam is not exposed to air.

(b) No ozone is produced.

(c) No radionuclides are produced.

Most of the electron losses occur during the capture process in the first accelerating section, at energies below 15 MeV, which is the typical threshold energy for activation by electrons. Thus, the only possibility for air activation is in the case of a failure of a magnet power supply causing the high energy (>15 MeV) electron beam to exit through the vacuum chamber, or activation of the electron beam dump. We calculate below the activation products for these situations.

Even without forced ventilation a complete air change usually occurs a few times per hour. Therefore, it is not possible to reach saturation levels for ^{3}H or ^{7}Be or approach the Derived Air Concentration (DAC) values for these isotopes and the only nuclides that need be considered for air activation are ^{13}N and ^{15}O. Saturation activities for these nuclides are 14000 and 1500 μCim^{-1} kW^{-1} respectively where m is the path length for bremsstrahlung in air in meters and the kW applies to the electron beam power. Note that γ-rays are mainly responsible for the air activation since the cross sections for electrons are much lower. In our case, two factors help to minimize air activation; first, we place lead close to the accelerator section or beam pipe where accidental electron losses and hence γ production occurs and second, most of our electron losses will normally occur at energies below 7 MeV where activation is not a problem. If we assume, conservatively, that 10% of our electron beam losses occur at energies >7 MeV and that the air gap between the accelerator and the lead shielding is 5 cm, then the electron beam power is 8 watts and the saturation activities for ^{13}N and ^{15}O are 5.6 μCi and 0.6 μCi, respectively. For a room volume of 400×10^{6} ml this will give a total air activation of 1.55×10^{-8} μCi/ml, which is 0.4% of the DAC value of 4×10^{-6} μCi/ml. In practice the beam loss will be detected by the remote read out radiation monitors located at sites where beam loss is likely to occur and the duty operator will take action to correct the fault in this accidental loss mode so saturation activities will not be attained.

All of the accelerator sections and beam line components are water cooled by closed loop, low conductivity water systems, each of which utilizes a small makeup water tank. In no case will the electron beam strike the water pipe directly, so water activation can only occur due to bremsstrahlung produced when electrons strike the copper discs of the accelerating structure or the stainless steel or aluminum beam pipe. Again, for normal operation, electron losses will occur at or near the injection energy so the γ-ray flux will be relatively low making activation of the machine components and the cooling water negligible. This is consistent with the observed results on the 120

MeV electron linac for the NSLS, which operates at about the same average beam current as the ATF linac and where the only activation that can be measured is in the momentum defining slits in the transport line where more than 50% of the electron beam is stopped. Levels of a few mR/hr can be measured at this location immediately after turning off the electron beam.

Activation of a copper beam stop utilized to stop the full electron beam are calculated from data in the report by W.P. Swanson. For 100 microbunches, 1nC/bunch at 6 pps, 120 MeV electron beam (average power 72 watts) we obtain saturation activities for Cu-61, Cu-62 and Cu-64 of 0.06, 1.08 and 0.36 Ci. This will give rise to a radiation field of 600 mR/hr at 1 m from the target immediately on beam turn-off without shielding and assuming no self shielding in the target. After about 1 hr this would decay to about 15 mR/hr. A lead shield around the target will readily reduce the radiation levels to acceptable values.

Under normal operation the electron beam does not pass through air so there is no possibility for ozone production. For the accidental case described above we calculate that without any air change we would reach a saturation level of 0.005 ppm for 8 hrs. This is well below the ACGIH TLV of:

- Heavy Work 0.05 ppm
- Moderate Work 0.08 ppm
- Light Work 0.10 ppm
- Heavy, Moderate, or Light Work ≤ (2 hours) 0.20 ppm

A NESHAPS permit has been issued for ATF operations but is not applicable (see Appendix III). The application was made for the air activation values given above and was based on the maximum capability of the accelerator in terms of its maximum output and worst case condition for passage through air. It is therefore unlikely, if not impossible, to exceed the permitted limits. In the unlikely event that these limits are exceeded, the proper notifications will be made as specified in the approval letter from the EPA dated October 19, 1989.

4.1.2.2 Soil Activation

A reorientation of the ATF beam line 1 in 2002 resulted in a 90^{o} bend toward the floor and the creation of a new stop to terminate the beam in. Because this orientation resulted in the forward directed beam pointed to the soil beneath the building, an evaluation of the potential for tritium and Na-22 production in soil was conducted which concluded that tritium and sodium-22 production in soil from operation of ATF beam line 1 does not require any additional engineering controls or monitoring. The analysis is given in Appendix V.

4.2 Electrical Hazards

In addition to the normal electric shock hazards present in the operation of electrical equipment operating off the building electrical distribution service at 115 volts single phase, there are a number of systems at the ATF that operate off 208 or 480 volts three phase. All cabinets housing these voltages are either secured by bolts or screws that can only be accessed internally, interlocked or are appropriately isolated. The high pulse voltages up to 45 KV found in the modulators driving the klystron amplifiers which provide the radio frequency power to drive the linear accelerator are all contained in cabinets with interlocked doors and automatic grounding of the high voltage, both mechanically and electrically, when an entry door is opened. In addition grounding sticks are available to manually ground the high voltage points within the modular enclosure prior to working on the system.

All ATF controls and instrumentation systems are well insulated and operate at voltages less than 24V rms. Magnet Power Supplies have outputs of 20Vdc or less with the exception of the 90° Magnet P.S. which is under 50Vdc.

Warning signs indicating high voltage hazards are posted in compliance with ES&H Standard 1.5.0.

4.3. Occupational Health Hazards

4.3.1 Non-ionizing Radiation Hazard

The radio frequency system for the linear accelerator utilizes two 25 MW peak power klystrons operating at a frequency of 2856 MHz. All of the high power rf is contained within the vacuum waveguide or accelerating cavities and poses no health hazard.

Magnetic fields of the order of 5 gauss at 1.4 meters developed by a large permanent magnet used for focusing the electron beam in the klystron and 5 gauss @ 0.2 meters by electromagnets used to bend the electron beam from the gun into the linear accelerator will be present. Signs warning of this hazard are posted near the klystron magnets and on the entry doors to the linear accelerator area where the electromagnets are housed.

4.3.2 Laser Hazard

A 2 mJoule per micropulse, up to 1500 micropulses pulses per second, 1 GW peak power, Nd:YAG laser used to excite the electron gun cathode is also a potential hazard. However, stability and timing requirements necessitate the laser light being enclosed in a temperature-regulated environment for the normal operational mode. Only trained laser users wearing protective eyewear may be inside the interlocked rooms used to contain the laser light. This is effectively a Class IV laser as defined in ANSI Z136.1-2000 and is operated as required by that standard, the BNL Laser Safety Subject Area and as described in the ATF Nd:YAG Laser Procedures.

There is a pulsed, terawatt peak power CO_2 laser, which is used to accelerate electrons in specially designed accelerator devices housed in the Experimental Area. It also presents a Class 4 laser hazard and is operated with the precautions given in the ATF CO2 Laser Procedures.

Similar precautions are taken for the light from the FEL experiments that may produce laser hazards from Class 2-4.

Other lasers may be used in experiments and are reviewed in compliance with the relevant subject areas, i.e. Work Planning and Control for Experiments and Operations, and Laser Safety.

4.4 Accident Assessments

4.4.1 Accident Assessment for the Linear Accelerator Systems

Extremely high levels of radiation, mainly in the form of bremsstrahlung and neutrons exist inside the linac shield so the potential for a serious radiation accident exists if the shielding is removed. Warning signs and a search procedure prior to start up will preclude any accident due to radiation. In order to assure shielding configuration control the moving of any shielding material must be reviewed and documented by the ATF Safety Officer and RCD Technician using the "Authorization for Work on ATF Accelerator Safety Systems."

There is also the potential for an accident due to electric shock. Preparation for this eventuality includes regular electrical safety training and training in the BNL ES&H Standard 1.5.1 (Lock-out/Tag-out Requirements) for all electronic technicians and others working with high voltage. Detailed training requirements are given in Section 4.0 of the ATF Handbook. The equipment is designed with the appropriate interlocks to prevent electric shock. LOTO is the policy at BNL and any working hot is not permitted unless covered by a "hot work permit." Detailed layout and shielding studies have been made and reviewed originally by the NSLS ES&H Committee, the Physics Department's ES&H Committee, and by the BNL Laboratory ES&H Committee. The shielding configuration for the entire accelerator housed in Building 820 low bay area is shown in Figures 5 and 6.

4.4.2 Accident Assessment for the Experimental Area

The electron beam striking any part of the beam pipe or lead shield in the beam line system produces very high levels of bremsstrahlung and neutrons. The protection systems described above are designed to prevent personnel from exposure to these levels. For an accident to occur, one or more of the following systems or procedures must fail.

1. The operations personnel would have to fail to carry out the prescribed search procedures.
2. The dual electrical interlocks on the entry door, which automatically turn off power to the linac r.f. system must have failed.
3. The dual electrical interlock that is activated when any entry door is opened and which automatically inserts the transport line beam stop must have failed.

All of the above procedures rely upon a proper search being carried out by the operations personnel. The only backup to this is the emergency off buttons which exist in all potential radiation areas and which will inhibit beam operation and revoke the interlock state.

4.4.3 Risk Assessment

ATF Risk Assessments have been carried out and are presented below:

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Electrical distribution system and electrical equipment
HAZARD: Possible contact with high voltage

Hazard Impact: Possible loss of life or serious injury to personnel

---

Risk Assessment prior to mitigation:

Severity : I (x) Catastrophic II ( ) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(x)Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I(x) High Risk II( ) Moderate III( ) Low Risk IV( ) Routine

---

Mitigating Factors: All power supplies are protected with physical barriers wherever there is a possibility of exposure to voltages exceeding 50 volts. In situations where extremely high voltages are present, such as the klystron modulators, door interlocks and automatic and manual grounding is provided. Working hot is discouraged and requires special training and approved procedures. High voltage and, or high current equipment is only accessed using BNL standard Lock-out Tag-out procedures. All affected personnel are trained to follow these procedures.

Risk Level following mitigation:

Severity : I(x) Catastrophic II( ) Critical III( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

---

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Accelerator, Beam Transport and Experimental Area
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety or equipment loss

---

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II ( ) Critical III (x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(x) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

---

Mitigating Factors: Most of the equipment associated with the accelerator and beam transport systems is metallic and is under concrete where it is somewhat protected from an external fire. Smoke and heat detectors are provided in all areas and there is an annunciator and signal system tied to the Site fire alarm system. Portable CO_2 and Halon 1211 fire extinguishers (UL rated 3A:ABC) are located throughout the area. The maximum travel distance to a fire extinguisher is 75 ft.

The Experimental Area is protected by a sprinkler system as well as having smoke and heat detectors.

All ATF personnel are trained in BNL Emergency Response Procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III( ) Low Risk IV(x) Routine

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Control Room
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety, equipment loss and program downtime.

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II ( ) Critical III (x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(x) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

----

Mitigating Factors: Smoke and heat detectors are situated in the Control Room and adjacent areas. Activation of any fire detection sensor automatically sounds local alarms and transmits an alarm to the BNL Fire and Rescue Group. Portable CO_2 and Halon fire extinguishers are located in the Control Room and adjacent area. There are two exits from the Control Room.

The total value of equipment situated in the Control Room does not exceed $300,000 and all of it could be replaced within a six month period.

All ATF personnel are trained in BNL Emergency Response Procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III( ) Low Risk IV(x) Routine

----

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Laser Equipment Areas
HAZARD: Personnel exposure to radiation from Class IV lasers

Hazard Impact: Eye or skin exposure to laser light

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II (x) Critical III ( ) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C(x) Occasional D( ) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II(x) Moderate III() Low Risk IV( ) Routine

---

Mitigating Factors: All personnel entering or working in laser equipment areas are required to wear protective eyewear. They are also protected from accidental exposure to laser radiation by transmitting the laser beams inside opaque enclosures and by providing interlocked areas to house the lasers. The laser safety and access control system is designed to be failsafe. Unauthorized entry into these secured areas will automatically cause a beam stop to block the beam so that the hazard is removed.

All laser operators undergo "Laser Safety Awareness" training and undergo an eye exam. As part of their training and certification, all personnel at the ATF must demonstrate an understanding of the procedures.

Risk Level following mitigation:

Severity : I( ) Catastrophic II(x) Critical III() Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D() Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III( ) Low Risk IV(x) Routine

SAD RISK ASSESSMENT

FACILITY: Accelerator Test Facility
SYSTEM: Electrical equipment, Laboratories and Laser Systems
HAZARD: Fire

Hazard Impact: Possible threat to personnel safety, equipment loss and program downtime.

Risk Assessment prior to mitigation:

Severity : I ( ) Catastrophic II ( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D(x) Remote
E( )Extremely Remote F( ) Impossible
Risk Category: I( ) High Risk II( ) Moderate III(x) Low Risk IV( ) Routine

---

Mitigating Factors: The trailer, the gun laser area and the equipment mezzanine are provided with smoke detection and also fire protection via a sprinkler system. Portable CO_2 and Halon 1211 fire extinguishers (UL rated 3A:ABC) are located throughout the area and the maximum travel distance to a fire extinguisher is 75 ft.

Gun and Linac modulators have been equipped with crash buttons to remove all sources of electrical power.

All ATF personnel are trained in BNL Emergency Response Procedures.

Exiting for fire emergencies is in compliance with the Life Safety Code NFPA101, 1994.

Activation of any fire detection sensor or alarm automatically sounds local alarms and transmits an alarm to the BNL Fire and Rescue Group.

Risk Level following mitigation:

Severity : I( ) Catastrophic II( ) Critical III(x) Marginal IV ( ) Negligible
Probability : A( ) Frequent B( ) Probable C( ) Occasional D( ) Remote
E(x) Extremely Remote F( ) Impossible
Risk Category : I( ) High Risk II( ) Moderate III( ) Low Risk IV(x) Routine

4.5 Worker Safety Controls

4.5.1 Introduction

All of the safety hazards at the Accelerator Test Facility are treated in essentially similar ways with regard to personal safety barriers such as shielding for radiation hazards and covered closed areas for electrical or laser safety. Locks, interlocks and securing procedures, control entry to radiation or laser areas.

4.5.2 Radiation Shielding

4.5.2.1 Gun, Linac and Transport Line Shielding

Here we are concerned with the problem of shielding to attenuate radiation produced by any of the loss modes described in Section 4.1.1 above. The shielding is designed to stop electrons and the resulting bremsstrahlung and x-rays in lead and then to absorb the neutrons thus produced in concrete or equivalent shielding. We estimate the shielding requirements for worst-case operation modes. Figure 5 shows the lead and concrete shielding for the linear accelerator and beam transport areas, and Figure 6 a cross-section of the linac and shielding.

We assume that the Linac testing and alignment operation with "dark current" and photo electrons will be carried out for 100 hours per month in a combination of the modes described in section 4.3.1. However, monitoring of radiation levels and magnet currents should preclude operation at some of these loss levels for long periods of time. Faults, which create unusual radiation loss, will be detected by Chipmunk radiation monitors, which are located at sites where such losses may occur. These are read out and alarmed in the Control Room and machine operators are given written instructions and are trained to take actions appropriate to the level recorded by these monitors. High loss levels will result in the beam being turned off while the reason for that loss is determined. Thus accidental losses will not be sustained for more than a few minutes. For shielding calculations these accidental losses may be neglected when compared with normal operational losses detailed below.

For normal operation of 250 hours per month at the low energy end, losses of 1.3×10^{19} electron-MeV/ month occur at the collimator in the low energy transport line just upstream of the accelerating sections at an energy of up to 7 MeV. This assumes conservatively that 20% of the electrons are stopped at the collimator with the rest passing through it to be accelerated to higher energies. In addition, an estimated 10^{16} electron-MeV/month of electron losses occur in the electron gun itself, due to "dark current" electrons, at energies up to 7 MeV. This requires shielding of the electron gun region as well as the transport line slit region. Losses of up to 5×10^{19} electron-MeV/month also occur at the beam dumps in the experimental hall assuming 50% of the operating time, or 100 hours per month is at the maximum energy and charge.

The "dark current" electrons, which are emitted from all copper surfaces of the electron gun where fields in excess of 50 MV/m to 100MV/m are present, produce x-rays when they strike the walls of the gun cavity. Since these electrons have energy < 7 MeV they are stopped by the copper walls and produce x-rays locally. The electrons are accelerated in all directions by the electromagnetic fields in the radio frequency cavity of the electron gun and receive energy gains, which vary from 0 to 7 MeV. The 7 MeV electrons are only obtained by synchronous acceleration from the cathode surface at which they are emitted by field emission, across the 1.5 cells of the electron gun essentially along, or parallel to, the gun axis. Electrons are also produced at the exit aperture by field emissions there and they are accelerated towards the cathode, though not synchronously, thus gaining energies of up to about 3 MeV, again essentially along or parallel to the gun axis in this reverse direction. The copper cathode and a large Pb plug stop these reverse electrons.

The electrons which travel synchronously along or near the axis will exit from the gun in the normal way, will be focused by the beam transport solenoids and are measured on the collimator faraday cup used to measure the normal electron beam. The measured peak "dark current" at 4.2 MeV/c in a test on the facility was 8 μA for 1 μsec. These forward electrons are only a small fraction of the beam of electrons which are accelerated from the photocathode which suffer from the same, or similar, loss modes. Shielding for the normal electron current will, therefore, take care of any "dark current" electrons emitted in the forward direction. "Dark current" electrons traveling in all other directions will, however, require proper shielding.

We assume that up to 8 μA peak "dark current" electrons are accelerated towards the cathode to an average energy of 3 MeV for a period of 1 μsec, 6 times per second and calculate the x-rays produced and shielding required for this case. According to NCRP Report No. 51 the shielding transmission ratio for x-rays produced by these electrons is given by:

$$B_x = 1.67 \times 10^{-5}\left[\frac{H_M d^2}{D_{1o} T}\right]$$

where D_{lo} is the absorbed dose index rate (rads m^2 min^{-1}) at a standard reference distance of 1 m from the source. H_m is the maximum permissible dose-equivalent or dose limit rate ($mremh^{-1}$), d is the distance between the X-Ray source and the reference point (meters), T is the occupancy factor. If we assume conservatively 2000 hrs/year of gun operation and a 20% occupancy factor for the gun area we need to reduce the dose rate limit to 0.25 $mremh^{-1}$ in order to obtain the 100 mrem per year dose limit for non-radiation workers as well as meeting the BNL administrative dose limit of 25 mrem/year for non-radiation workers. Substituting these values in the above equation gives $B_x = 2 \times 10^{-3}$ for a lead shield starting 15 cm and ending 30 cm from the source. This would require 5" of lead in the forward direction. X-Ray radiation in the sideways (90E direction) is down by a factor of 4 compared to the (0E) case so 4" of lead is sufficient in that direction. In practice, only a small fraction of the "dark current" electrons reach the full 3 MeV energy at the cathode and the shield distance from the cathode is 30 cm rather than the 15 cm for the sideways (90E) direction so 4" of lead is an adequate shield in all directions.

The neutron yield per unit beam power, mainly arising from giant resonance neutrons, is nearly independent of electron energy at energies above 20 MeV and is taken from the calculations of W.P. Swanson (Health Physics 37 (1979) pages 347-358) as 2.1×10^{12} neutron/k Joule for the full Linac operational loss mode. For 7 MeV operation we are below the threshold for neutron production so no

$$\phi = \frac{5 \times 10^{19}\dfrac{MeV}{month} \times \dfrac{12\ month}{year} \times 2.1 \times 10^{12}\dfrac{neutrons}{kJoule} \times 1.6 \times 10^{-16}\dfrac{kJoule}{MeV}}{4\pi(200cm)^2}$$

$$= 4x\,10^{11}\,neutron/\,cm^2\,year$$

neutrons are produced. For the experimental hall beam dump:

We will assume that ordinary concrete is used to shield the neutrons thus produced and use the formulation of NCRP Report #51 to calculate the shielding thickness required to reduce the dose level at normally occupied areas of Building 820 and the Experimental Hall to 100 mRem per year.

To reach this number a conversion factor of 2.5 x 10^{-13} rem cm^2 must be applied to the fluence at the Linac beam stops. This gives a value of 350 g/cm^2 or 148 cm of concrete for the beam stop regions. The appropriate shielding is provided for these areas as described in Section 4.5.2.2 of this document and the procedure for securing the Linear Accelerator Area is in Section 4.5.3.1.2.

4.5.2.2 Beam Transport Lines and Experimental Area

4.5.2.2.1 Introduction

An overview of the neutron, bremsstrahlung and x-ray shielding for the Accelerator Test Facility is given in Section 4.5.2. This section expands on that information giving details of lead and concrete shielding configurations for the experimental hall and the linac transport area of Building 820. Source terms and shielding calculations are also presented.

4.5.2.2.2 Operating Parameters

Using the current shielding, the linear accelerator has been approved to operate at 10% of maximum, i.e. 120 MeV and 60 nanocoulombs per second, time averaged over an increment of 1 hour (alternatively no more than 219 microcoluombs in one hour) by the Laboratory ES&H Committee (LESHC Minutes of Meeting 02-01, December 3, 2002). For the purposes of these calculations, however we consider energies up to 120 MeV with a maximum pulse repetition frequency of 6 Hz and a maximum charge of 1.0 nC in each of 100 microbunches contained in a 3.5 μsec macrobunch. Therefore, the maximum number of electrons accelerated to 120 MeV is 3.6 x 10^{12} per second. Under normal operating conditions, almost all of these electrons would reach the beam dumps situated in the experimental hall or at the end of the transport lines in the Building 820 high energy beam transport region (see Figures 1 and 2). Under certain conditions, some beam is lost at points along the beam line, such as near quadrupoles, or dipole bending magnets, or at collimators utilized to clean up the tails of the electron beam. We shall assume that up to 5% of the electron beam is lost at a single point in any of the above locations in any part of the beam transport system and calculate the shielding required to reduce the radiation levels to less than 100 mrem for the year. We shall further assume that the facility operates for 2400 hours per year with 1200 hours of operation at levels where the radiation levels are insignificant, i.e. less than 10^7 electrons per second accelerated to full energy.

4.5.2.2.3 Shielding Estimates

The primary lead shielding is for bremsstrahlung γ-rays produced by electrons striking the stainless steel of the beam transport pipe or the copper of the linac structure. Lead shields are placed at locations where such electron losses may occur. In essence, the primary γ-ray source is the lead shield itself since the energetic electrons easily pass through the beam pipe with little loss in energy. The 2" to 4" thick lead shield also gives rise to the production of photo neutrons which are then shielded by concrete enclosures around the lead. Any γ-rays which pass through the primary lead shield are readily stopped in this concrete shield wall so we will concentrate on the neutron shielding calculations.

The calculations presented in the Section 4.5.2.1 for the beam stops in the experimental area, and in the linac tunnel in Building 820, estimated that, after the electrons were stopped there, for the above operating conditions, slightly less than 5 ft. of ordinary concrete is required to reduce the levels outside the shield to 100 mrem per year. If 5% of the beam can be lost at any point along the transport line this requires 3.5 ft. of ordinary concrete to reduce the radiation levels outside the shield to 100 mrem/year. In the beam transport area of Building 820, there is a mezzanine above this line which contains accelerator equipment. The shield above this line must also be 3.5 ft. thick. In the experimental hall, the roof thickness must be sufficient to handle "skyshine" so we will use the methods presented in NCRP Report #51 to calculate the required shielding. (Here, we assume that the beam stops in this area are shielded by a full five foot of ordinary concrete or equivalent in all directions.)

4.5.2.2.4 Shielding for Skyshine of Neutrons

If we assume a steady 5% beam loss near a quadrupole or dipole bending magnet in either of the high current transport lines utilized for FEL or IFEL studies in the experimental area, and assume that this electron loss occurs in the lead shield, we can obtain the total neutron yield from Appendix F.3 of NCRP Report #51 as 2×10^{11} neutrons sec^{-1} μA^{-1}. The total number of electrons lost per second is 5% of 3.60×10^{12} or 1.8×10^{11} which is equivalent to an electron current of 1.8×10^{11} / 6×10^{12}, or approximately 3×10^{-2} μA. Then the neutron yield for all directions is $Y = 2 \times 10^9$ neutrons per second.

From Appendix F.4 we obtain the neutron fluence rate is $\varphi = Y_{sr\text{-}1} \times 10^{-4} / d^2$ where d is the distance from the source in meters. Also from F.4 we see that $Y_{sr\text{-}1,90}/Y_{sr\text{-}1,0} = 2$ so we obtain the neutron fluence φ_o at 90E as:

$$\phi_o = \frac{2x2x\,10^9\,x\,10^{-4}}{4\pi\,d^2}\,neutrons\; m^2\,cm^{-2}\,\sec^{-1}$$

Since the experimental area roof is 1.4 m above the beam line, or source of neutrons, this gives $\varphi_o = 1.6 \times 10^4$ neutrons m^2 cm^{-2} sec^{-1}.

Section 4.5.2 gives the roof shielding neutron transmission ratio, B_{ns}, for skyshine up to 20m from the source as:

$$B_{ns} = 3.3\,x\,10^{-3}\left[\frac{\dot{H}_M\,d_i^{\,2}}{\phi_o\Omega}\right]$$

Where $\dot{H}_m$ is the maximum allowable dose rate limit in $mremhr^{-1}$ and d_i is the distance between the source and 2 meters above the roof shield, Ω is the solid angle in steradians subtended by the neutron source and the shielding walls. We shall conservatively assume this angle to be 2π so that for $\dot{H}_m$ =100 mrem/1200 hrs we obtain:

$$B_{ns} = 3.3\,x\,10^{-3}\left[\frac{\frac{100}{1200}(3.5\,)^2}{2\,x\,10^4\,2\pi}\right] = 2.7\times10^{-8}\,rem\;cm^2$$

If we apply this to Appendix F.8 we obtain a concrete slab thickness of 50 gcm^{-2} or 22 cm of concrete. These shielding thicknesses for neutrons are more than adequate shielding for γ-rays which are primarily shielded by the lead near the beam line. For structural purposes the roof concrete thickness provided for the Experimental Area is 1.25 ft. or greater.

4.5.2.2.5 Entry Mazes

In order to enter the experimental area it is necessary to pass through a maze. Both the laser equipment area and the entrance foyer adjacent to the entrance from the Control Room area are considered to be controlled areas, while the experimental area is a high radiation area when beam is present. The nearest source of neutrons in the experimental area to either exit aperture is about 3 meters so the neutron fluence rate at the maze inner aperture is less than 10^3 neutrons cm^{-2} sec^{-1}. Both mazes are double legged and have a width of 3 ft. and a height of 7.5 ft. Section 4.4.2 gives the neutron transmission ratio through ducts, B_{nm}, as:

$$B_{nm} \leq \frac{270\, \dot{H}_m}{K\, \phi_m} \quad \textit{where } \dot{H}_m \textit{ is} \leq 5 \textit{ mrem/hr.}$$

and where K = 8 for a two-legged maze. Thus for our case, we obtain:

$$B_{nm} \leq \frac{270 \times 5}{8 \times 10^3} \quad \textit{i.e. } B_{nm} \leq 0.17$$

From Appendix F.11 we obtain a center line distance of $2\sqrt{3x7.5}$ or 9 ft. in order to provide acceptable levels at the entry doors to the experimental area.

4.5.2.2.6 Shielding Design and Equipment Access

4.5.2.2.6.1 High Energy Beam Transport in Building 820

The shielding layout for the linac and low energy beam transport systems is given in Section 4.5.2.1. The shielding for the high energy beam transport system is shown in Figures 1, 5 and 6. In order to align the transport elements with the shielding in place, it is necessary to provide a narrow accessway alongside the beam lines which is entered by removing a plug door. This plug door is on rollers with a winch and cable arrangement for opening it. The door is electrically interlocked so that the rf system modulator cannot be turned on while the door is removed unless two independent interlock circuits which interrupt the modulator power supply are satisfied. It can be seen from Figures 5 and 6 that local lead shielding is provided near quadrupole and dipole magnets and around collimating slits. At least 3.5 ft. of light concrete or heavy concrete equivalent is provided as required by Section 3 of this document and 5 ft. equivalent thickness is provided for the two beam stops as calculated Section 4.5.2.1.

Because the accessway is potentially a high radiation area, a search and secure procedure and emergency stop buttons are provided for this area. Regular and emergency lighting and a telephone have been provided for the accessway.

4.5.2.2.6.2 Experimental Hall Shielding

The shielding for this area is shown in Figure 4. Local lead γ-ray shielding is provided near quadrupole and dipole bending magnets and beam line collimators as necessary. A minimum of 3.5 ft. of concrete or equivalent is provided in the forward, backward and sideways directions for all loss points. A roof thickness of 1.25 ft. or greater of concrete is provided over the whole experimental area and entry mazes of greater than 9 ft. in length are provided at both entry points. All entry doors have dual safety interlocks. Sprinklers, emergency and regular lighting and air conditioning are provided for this area. Beam stop shielding is provided as detailed in Section 4.5.2.1. The beam stops are entirely in vacuum so no air activation from primary electrons is possible.

4.5.3 Accelerator Interlocks and Security

4.5.3.1 Radiation Security

4.5.3.1.1 Securing the Linac Gun Area

Since the electron gun area is a controlled area and has the potential of becoming a high radiation area if certain lead shielding is removed, it is a fenced and locked area. Removal of lead requires a safety authorization form, a copy of which is given as Appendix IV. The gun hutch (see Figure 7) is secured using one of the procedures described in the ATF Laser Interlock System Search Procedure. Completion of the search culminates by depressing of a button on a control box adjacent to the last exit door either inside or outside the gun hutch. If anyone for any reason wishes to stop operation of the laser they may do so by depressing any of a number of emergency stop buttons situated at convenient and clearly marked locations in and around the gun hutch, the Nd:YAG room and in the experimental area. The gun hutch door is provided with standard door hardware to allow for fast exit in an emergency.

If the gun hutch entry door is opened while the search is being carried out, the search is aborted and has to be restarted.

4.5.3.1.2 Securing the Experimental Area

Since this is a primary radiation area it is protected by stopping the electron beam in either a fixed or movable beam stop situated in the high energy beam transport line Any attempt to enter the experimental area will cause the movable beam stop to be inserted and will also automatically turn off the contactor providing power to the klystron modulators. Dual electrical interlocks are provided on both the electron beam stop and the entry doors to the experimental area. Each electrical circuit operates an independent set of power contactors in the supplies to the modulators. One of the electrical circuits also inserts a beam stop situated downstream of the linac.

Before startup of the accelerator a search is made of the experimental area. In order to ensure a proper search, reset buttons are provided which require the person carrying out the search to cover all regions of the experimental area. These have to be reset in a prescribed sequence, and in a prescribed time. The person carrying out the search exits through the entry door situated either at the northeast or southwest corner of the experimental area. After exiting and closing the door, a reset button must be pressed which sets off an annunciator in the experimental area that sounds for 15 seconds. If anyone for any reason wishes to stop operation they may do so by depressing any of a number of emergency stop buttons situated at convenient and clearly marked locations within both the Linac and experimental buildings. Both entry doors are interlocked and both are provided with an emergency panic release system to allow fast exit in an emergency. If either of the entry doors is opened while the search procedure is in progress the search is automatically aborted and has to be restarted. The detailed procedure for securing the ATF Experimental Area is given in the ATF Laser Interlock System Search Procedure.

In order to carry out beam studies in the straight ahead or 20 degree beam line by stopping the beam before the experimental hall, it is necessary to insert the movable beam stop. Entry to this area is via a dual electrically interlocked movable concrete door. The Operation of the ATF Procedure describes the requirements for entering and securing this area. When the movable beam stop is inserted and the plug door is in place with the interlock complete it is possible to operate the modulator and low energy beam transport systems in order to carry out beam diagnostic studies at >5 MeV while the experimental area is open. These procedures must be followed in order to operate in this Mode.

All ATF Radiation Interlock Systems had originally been reviewed and approved by the BNL Interlock Review Committee, later updates were reviewed and approved by the NSLS, and currently, the C-AD Interlock Group has the responsibility.

4.5.3.2 Securing the Laser Equipment Rooms

Some of the lasers housed in the laser rooms are classified as Class IV lasers as per ANSI Z136.1-2000. Therefore, all entry doors to the laser equipment rooms are electrically interlocked so that an unauthorized entry will cause a beam stop to be inserted in the laser beam path. The ATF Laser Interlock System Search Procedure describes how laser areas are secured. In addition, persons working in this area are required to wear protective eyewear whenever the lasers are capable of emission. They are also required to undergo training as specified in Sections 4.00 and 4.01 of the ATF Handbook. Furthermore, the beam transport path between rooms is enclosed, with interlocks being provided for the enclosures. The ATF Procedures related to lasers give an overall description of the lasers to be used in the experimental program at the ATF and all associated safety, operation and maintenance procedures.

5. QUALITY ASSURANCE

The Accelerator Test Facility is part of the Physics Department. . The BNL Quality Assurance Program applies to the work performed on the project. The ATF management is responsible for the quality of construction, the operation of the equipment and the work processes in the facility. Responsibility for quality is delegated through the line staff positions and they are responsible for the quality of their own work. ATF accelerator components are evaluated for quality assurance categories A-1 through A-4 as per BNL QAC-301. The ATF shall comply with the required QA elements of DOE Order 414.1.

6. DECOMMISSIONING AND DECONTAMINATION PLAN

At the appropriate time a full decommissioning and decontamination plan will be developed using the Subject Area, Work Planning and Control for Experiments and Operations. The ATF is a low hazard facility with standard industrial hazards, lead for shielding, and very low levels of activation are expected at ATF decommissioning.

7. ASSOCIATED DOCUMENTATION

1. BNL Standards Based Management System
2. BNL ES&H Standards
3. BNL Subject Areas
4. Physics Department Policies and Procedures
5. ATF Handbook
6. ATF Procedures

FIGURE 1
ACCELERATOR TEST FACILITY LAYOUT/ BUILDING 820

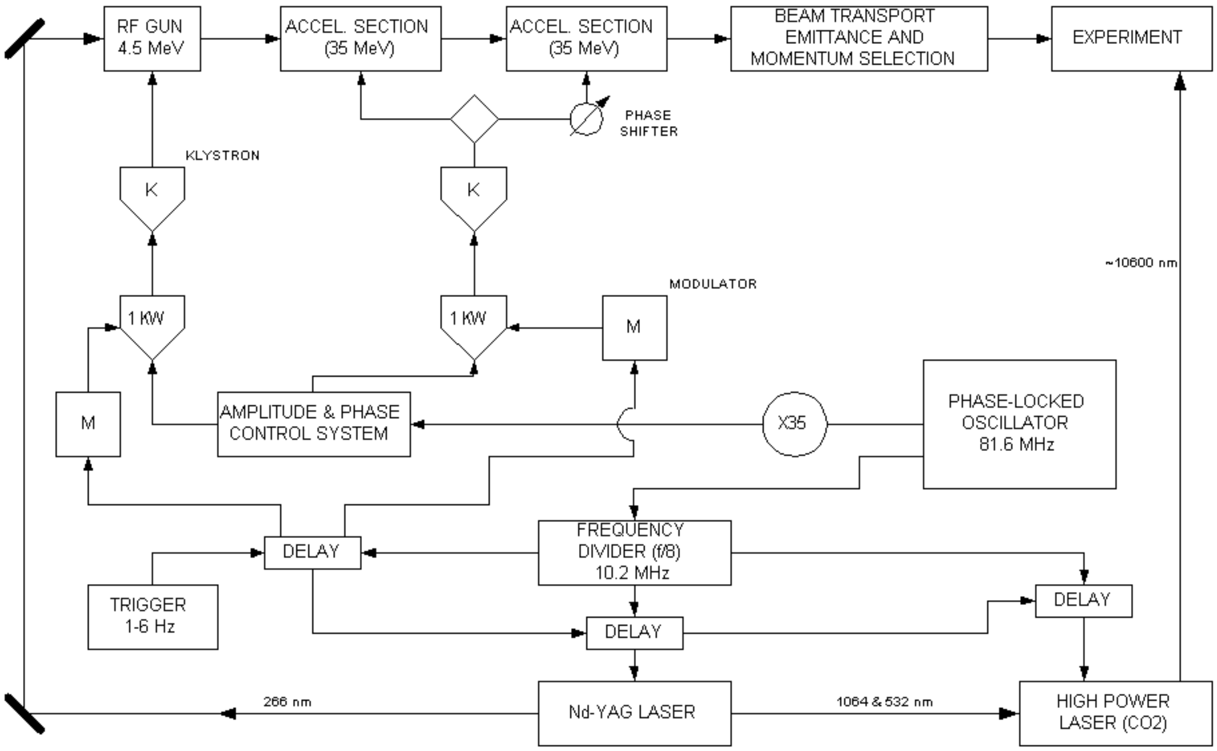


FIGURE 2
Schematic Diagram of the Accelerator Test Facility

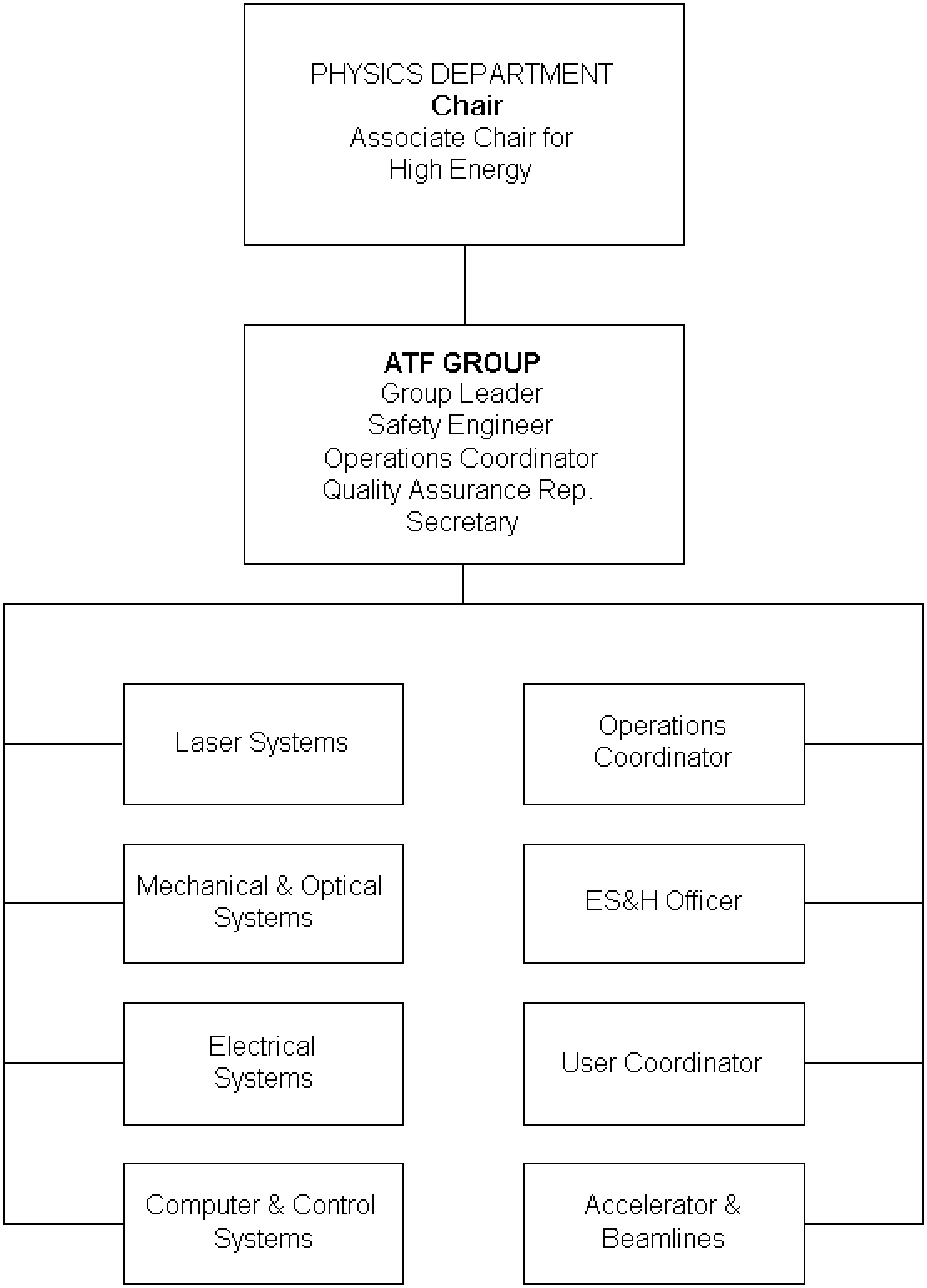


FIGURE 3a: ATF Organization Chart

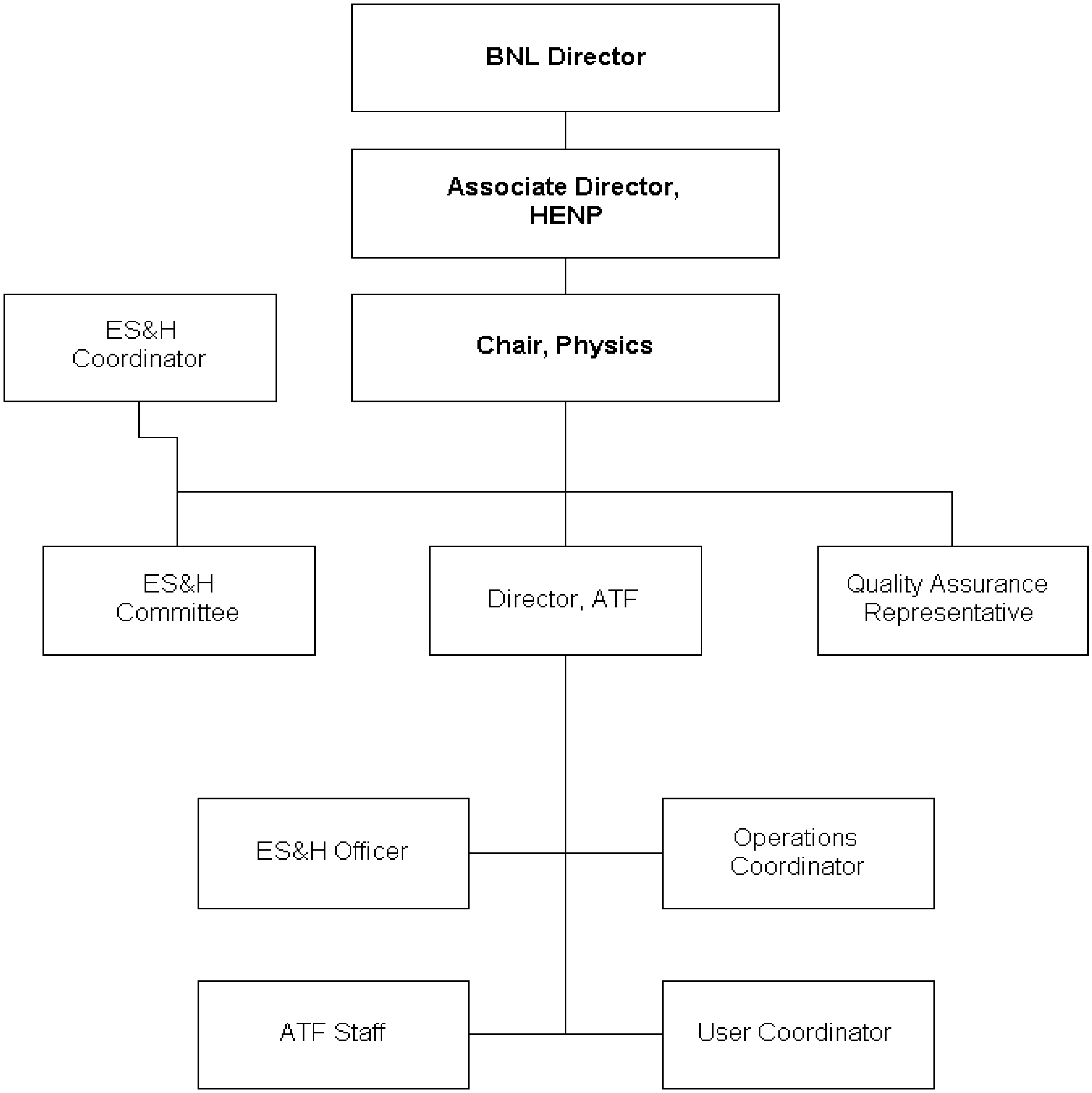


FIGURE 3b: Safety Organization Chart
Accelerator Test Facility

No. 2-00

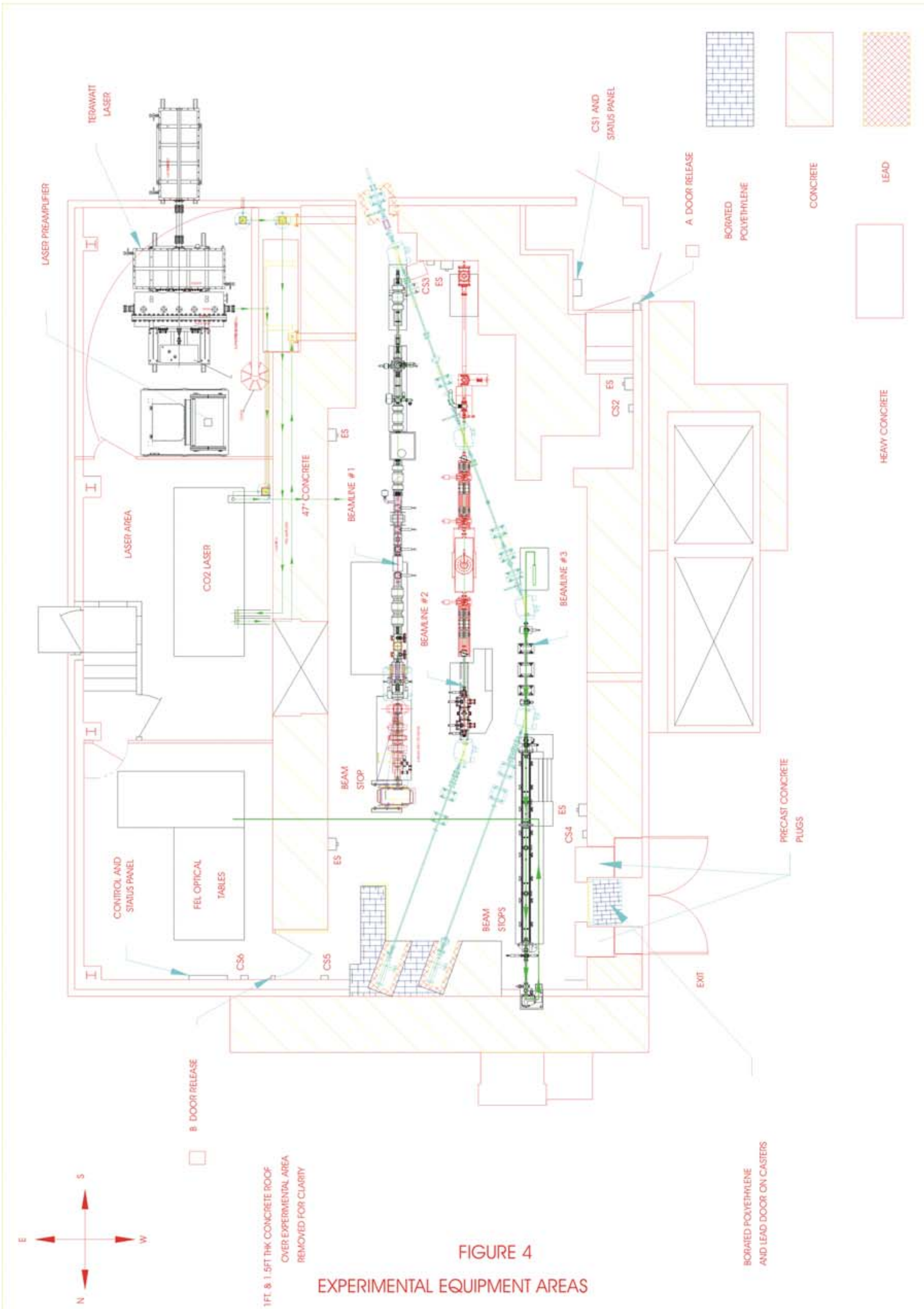


FIGURE 4
EXPERIMENTAL EQUIPMENT AREAS

Revised January 12, 2004

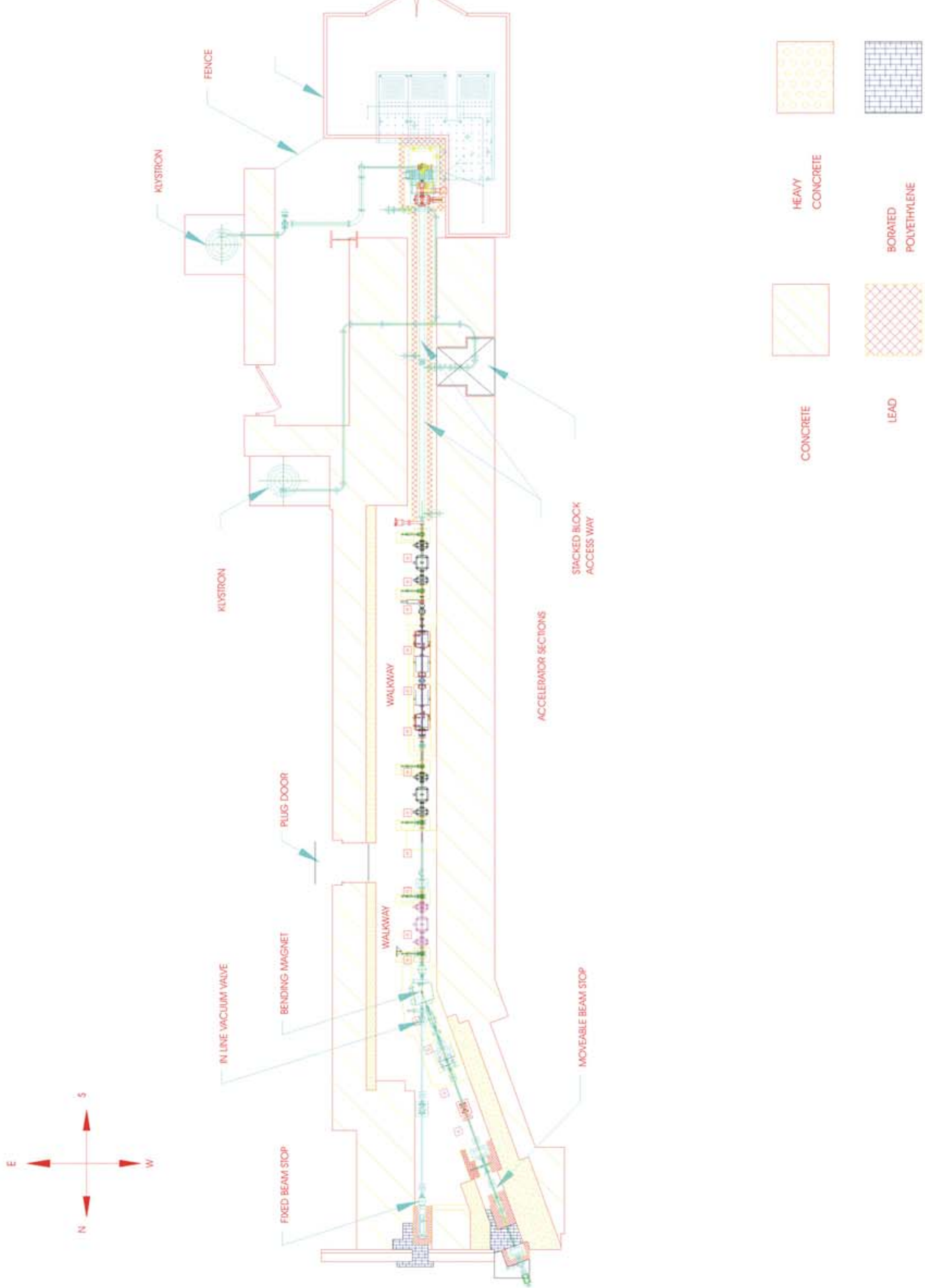


FIGURE 5

BUILDING 820 SHIELDING

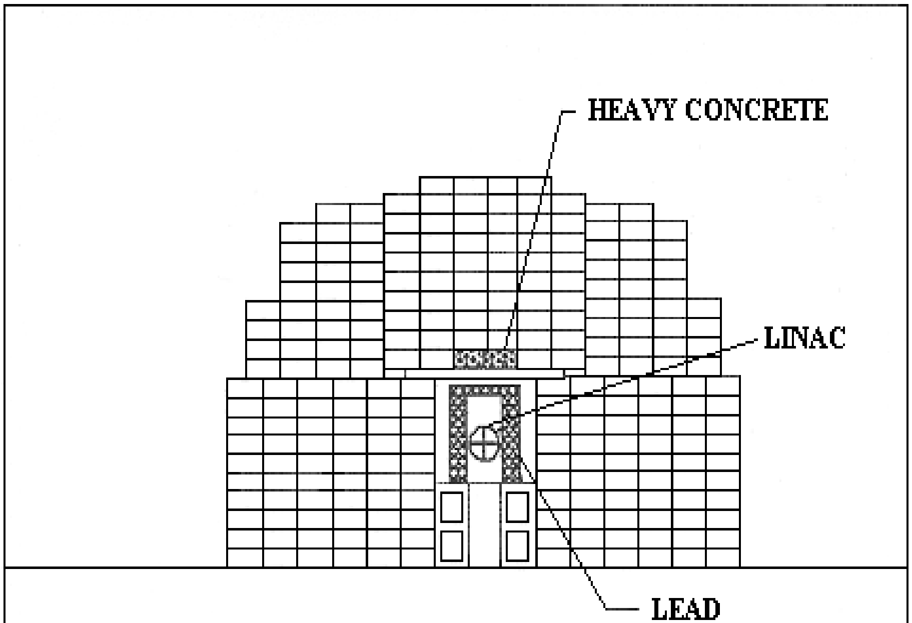


FIGURE 6A
SECTION AT LINAC

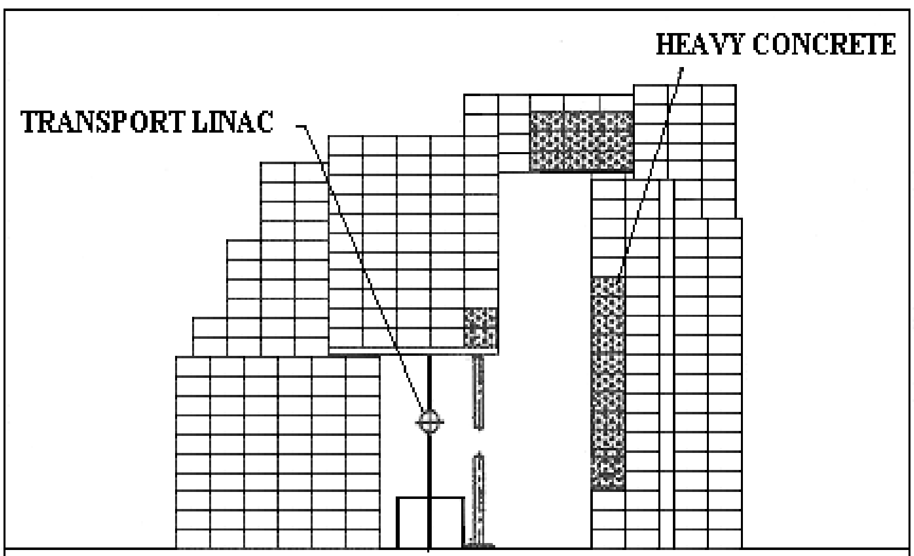


FIGURE 6B
SECTION AT TRANSPORT LINAC

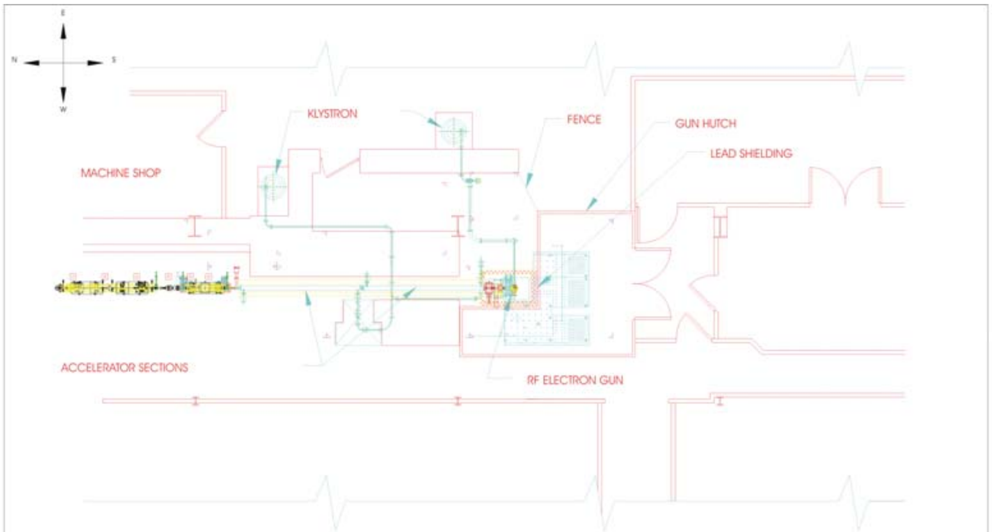
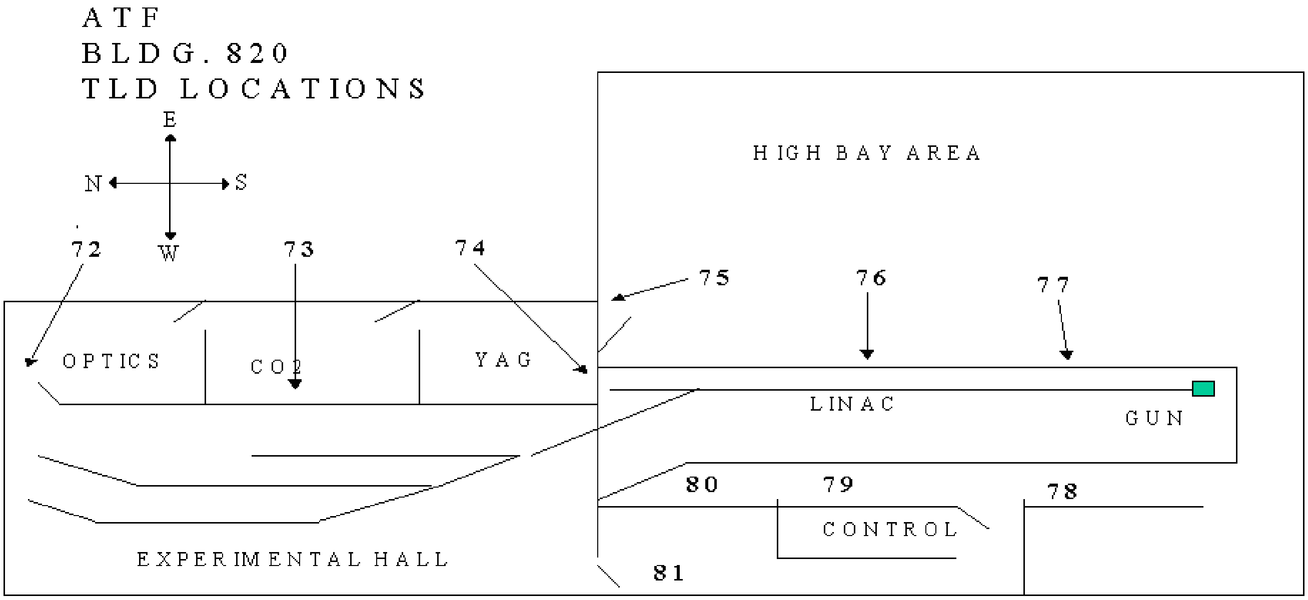


FIGURE 7

ELECTRON GUN AREA ARRANGEMENT



	TLD 72 Neutron	TLD 72 Gamma	TLD 73 Neutron	TLD 73 Gamma	TLD 74 Neutron	TLD 74 Gamma	TLD 75 Neutron	TLD 75 Gamma	TLD 76 Neutron	TLD 76 Gamma
1995	**13**	**40**	**3**	**4**	**26**	**212**	**7**	**0**	**11**	**3**
1996	**14**	**122**	**4**	**1**	**8**	**148**	**6**	**0**	**8**	**2**
1997	**5**	**18**	**3**	**0**	**7**	**89**	**3**	**2**	**4**	**7**
1998	**5**	**110**	**1**	**0**	**7**	**3**	**3**	**0**	**3**	**0**
1999	**94**	**43**	**9**	**34**	**7**	**1**	**1**	**9**	**3**	**4**
2000	**11**	**54**	**3**	**0**	**11**	**6**	**4**	**0**	**3**	**0**
2001	**26**	**68**	**3**	**0**	**3**	**9**	**0**	**0**	**2**	**0**
2002	**3**	**8**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**

	TLD 77 Neutron	TLD 77 Gamma	TLD 78 Neutron	TLD 78 Gamma	TLD 79 Neutron	TLD 79 Gamma	TLD 80 Neutron	TLD 80 Gamma	TLD 81 Neutron	TLD 81 Gamma
1995	**6**	**0**	**12**	**7**	**12**	**5**	**160**	**37**	**5**	**2**
1996	**1**	**1**	**5**	**5**	**9**	**0**	**145**	**38**	**5**	**0**
1997	**1**	**7**	**3**	**11**	**6**	**0**	**206**	**35**	**3**	**0**
1998	**2**	**1**	**2**	**0**	**3**	**0**	**29**	**4**	**2**	**0**
1999	**3**	**7**	**3**	**7**	**19**	**4**	**17**	**14**	**10**	**8**
2000	**3**	**14**	**4**	**2**	**4**	**3**	**60**	**7**	**3**	**0**
2001	**2**	**0**	**4**	**0**	**3**	**0**	**84**	**2**	**4**	**0**
2002	**0**	**0**	**0**	**0**	**0**	**0**	**23**	**0**	**1**	**0**

FIGURE 8: ATF TLD Totals for the Years 1995 Through 2002 (Annual Totals are in mRem)

Appendix I

Life Safety Code Analysis
Brookhaven National Laboratory
Building 820, Accelerator Test Facility

Prepared by: J. A. Eckroth

Reviewed by: J. W. Levesque

Date of Survey: October 3, 1997
Updated: February 3, 1999

Date of Report: October 29, 1997
Updated: February 3, 1999

Conferred with: N. Gmur, Environment, Safety and Health Coordinator, NSLS
B. Cahill, Point of Contact at Building 820

Scope

This is an analysis of the level of life safety (i.e.: the ability of occupants to exit during a fire) and compliance with the Life Safety Code (LSC)[1]. The analysis of Bldg. 820 in this report is limited to those areas of Bldg. 820 occupied by the Accelerator Test Facility (ATF). Compliance with the Life Safety Code is one of the performance objectives of DOE Order 420.1[2].

Summary

The uses of the building, as described under "Occupancy", below, are based on a field survey and on discussions with N. Gmur and B. Cahill. The building complies with most aspects of the LSC and is acceptable for continued occupancy.

Recommendations

There are no new recommendations as a result of this updated survey. All recommendations made on previous surveys have been closed out.

Analysis

Building Construction

The ATF portion of Building 820 is a one story building with a mezzanine and is of insulated metal panel and steel frame construction. Interior walls are a combination of concrete block, gypsum *board on wood and steel studs, and metal and composite panels.*

A building layout is shown on the diagram in Attachment 1.

Fire Protection

The ATF area *of Building 820 is protected with a combination of automatic sprinklers, fixed* temperature/rate of rise heat detectors, smoke detectors, and manual fire alarms. Alarms are arranged to annunciate: locally, at BNL Fire/Rescue Headquarters (Building 599), and at BNL Police Headquarters (Building 50).

---

[1]National Fire Protection Association No. 101, Life Safety Code, 1994 Edition

[2]US Department of Energy Order No. 420.1, Facility Safety, 10/13/95

Classification of Occupancy

The overall occupancy classification of the ATF area of Building 820 for LSC purposes is General Industrial. The offices and control room located within Bldg. 820 are incidental to the main occupancy. No high hazard operations are associated with the ATF areas in Building 820.

Occupant Load

The ATF facility including the mezzanine and trailers covers approximately 8400 sq. ft. of floor area. Based on an occupancy load factor of 100 sq. ft./ person, the entire occupancy load for this area of Bldg. 820 is 84 people. This occupancy load is for LSC analysis and does not necessarily reflect the actual occupancy load of the building which under normal conditions is expected to be less.

Means of Egress Components

The doors in Bldg. 820 provide for an adequate means of egress in accordance with the LSC. In addition, most of the stairs in Bldg. 820 comply with the requirements of either Class A or Class B stairs as allowed by the LSC for an existing facility.

The landing on the Laser Room side of the 36 inch exit access door into the new YAG Laser Room is 43.5 inches wide by 25 inches deep. In addition, the width of the two steps in the Laser Room are only 25 inches. The LSC normally requires a landing equal to the width of the door on both sides of the door and the width of the stairs to be 36 inches. The current arrangement of this landing and the steps is considered tolerable because of the limited use of the door, landing, and steps into the Laser Room.

The second means of egress from the mezzanine area is via alternating tread device. The use of this device as a secondary means of egress from the mezzanine is tolerable because the mezzanine is not a normally occupied space. When the mezzanine is occupied, it is not occupied by more than three persons and all occupants are capable of using the alternating tread device.

There are no ramps, horizontal exits, exit passageways, fire escape stairs, or fire escape ladders serving this building.

Capacity of Means of Egress

Exit capacity is based on the calculated occupancy load and on exit width factors, such as 0.2 inches/person for horizontal components and 0.3 inches/person for stairs. With the exception of the one item noted below, there is adequate exit width from the ATF area of Building 820 and from each area within the building to accommodate the calculated occupancy load.

The minimum width of all means of egress in an industrial occupancy, including exit egress width, should be no less than 28 in (LSC 5-3.4.1). There is one location in the ATF areas of Bldg. 820 where the exit egress width is reduced to less than 28 in. The location is in the Experimental Area of the ATF where a survey pole is periodically placed in the egress path to allow alignment of the beamlines in this area. It was indicated by facility personnel that the survey pole is only installed when surveys are taking place and is removed when not in use. This incidental obstruction to the egress path during limited time periods while surveys are being performed is considered tolerable.

Appendix I (Cont.)

LSC, Building 820, Page 3

Number and Arrangement of Means of Egress

All ATF areas of Building 820 are provided with an adequate number of properly arranged exits. Common paths of travel and dead end corridors are within the 50 ft. maximum LSC allowance.

Travel Distances to Exits

Total travel distance to an exit from all ATF areas of Building 820 are within the 200 ft. LSC limitations for General Industrial occupancies.

Discharge from Exits

All required exits in the ATF area of Building 820 discharge directly to a public way or at an exit discharge.

Emergency Lighting and Marking of Means of Egress

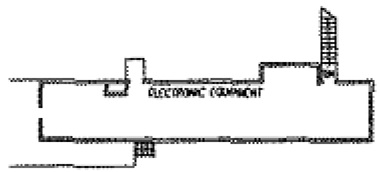
Adequate emergency lighting is provided in the exit access areas of Building 820. The required means of egress for this facility are adequately marked.

Protection of Vertical Openings

There are no vertical openings in this one story building.

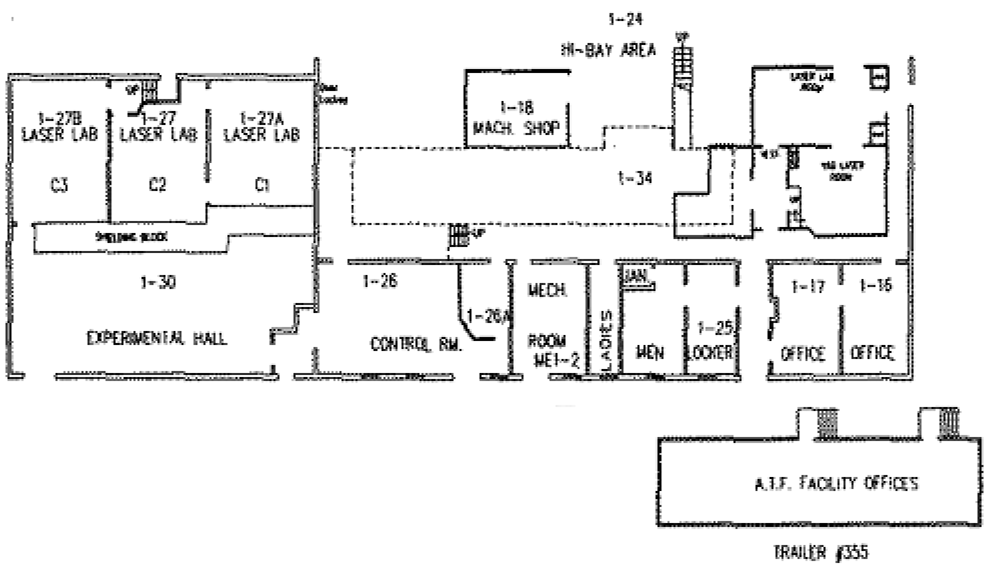
Appendix I (Cont.)

LSC, Building 820, Attachment 1
Page 1 of 1



MEZZANINE

N <——



Not to Scale

Appendix II

Fire Protection Assessment / Fire Hazard Analysis
Brookhaven National Laboratory
Building 820, NSLS Accelerator Test Facility

Prepared by: J. A. Eckroth

Reviewed by: J. W. Levesque

Date of Survey: October 3, 1997
Updated: February 11, 1999

Date of Report: March 16, 1998
Updated: February 11, 1999

Conferred with: I. Ben-Zvi, ATF Head
N. Gmur, Environment, Safety and Health Coordinator - NSLS

Purpose/Scope

The purpose of this assessment is to evaluate the facility related fire protection aspects of the Accelerator Test Facility (ATF) areas of Building 820 to ensure compliance with DOE fire protection criteria. DOE fire protection criteria are outlined in DOE Order 420.1[1]. A Fire Hazard Analysis, required for the Safety Analysis Document for this facility, is incorporated in this assessment.

Summary

The current and proposed use of the ATF areas of the building, described under "Occupancy and Associated Fire Hazards" below, are based on a field survey, a review of the planned installations, and discussions with I. Ben Zvi and N. Gmur. The level of fire protection in most of the non-ATF areas of Bldg. 820 and in several areas of the ATF are not sufficient to classify this building as an "improved risk", one of the overall objectives of DOE Order 420.1. Four items exist for which improvement measures are recommended.

The recommendation for the installation of automatic sprinkler protection throughout the unprotected areas of Bldg. 820 is beyond the scope of the department. However, the recommendation for the installation of sprinkler protection is included in this report to ensure an awareness of the loss potential that exists due to the lack of full sprinkler protection. The recommendation for the installation of automatic sprinkler protection in Bldg. 820 has been added to a proposed line item funded BNL site-wide fire protection improvements project (Phase IV - ADS A92D0127).

Recommendations

1. Status of Recommendations from Previous Survey

FHA97-820-1 With the exception of those areas recommended to be protected by a clean agent fire suppression system, automatic sprinkler protection should be provided throughout all areas of Bldg. 820 which are currently not protected. A preaction sprinkler system should be installed in the areas of ATF containing high value equipment susceptible to water damage (ADS A92D0127).

FHA97-820-2 To the extent possible, the Class 4 laser installations and their use in Bldg. 820 should comply with the recommended practices in NFPA 115, Laser Fire Protection.

[1]US Department of Energy Order No. 420.1, Facility Safety, 11/16/95

FPA/FHA, ATF area of Bldg. 820, page 2

FHA97-820-3 This recommendation has been completed and is considered closed.

FHA97-820-4 A clean agent automatic fire extinguishing system such as FM200 or Inergen should be installed in the Yag Laser Room to provide protection for the high value electronic equipment located within this combustible enclosure. The adjacent Laser Lab Room and Vestibule should also be protected by the clean agent fire extinguishing system due to the combustible construction of these areas.

FHA97-820-5 To minimize the exposure of the Yag Laser Room and the Laser Lab Room from an external fire, the exterior surfaces of this combustible enclosure should be covered with a fire rated barrier such as gypsum wallboard or by a noncombustible material such as sheet metal (P.E. Job No. 8625A).

2. New Recommendations Resulting from the Current Survey

There are no new recommendations as a result of the current survey.

Analysis

1. Construction

Building 820 is a one-story steel framed building with insulated metal panel walls on a poured concrete slab. The original portion of the building was constructed in 1957. The roof is partially a Class II insulated metal roof deck and partially a standing seam metal roof deck. The total building area is approximately 25000 sq. ft. with the ATF occupying approximately 4225 sq. ft. of the total area. The ATF area is contiguous with the other areas of Bldg. 820.

There are no major fire rated interior walls associated with Bldg. 820. The control area for the ATF is located in a room adjacent to the accelerator, with no fire rated separation (see Section 2.2.1 for details). A clean room that houses the YAG laser system is located in the south section of the area occupied by ATF. The clean room is constructed of a 3 in. thick polystyrene core wall system covered with a vinyl covered hardboard. The wall panels have a Class C flame spread rating and are considered to be combustible.

1.1 Fire Barrier Integrity

There are no fire barriers required for the ATF areas of Building 820. As indicated above, the ATF area of Building 820 is contiguous and open to other areas of Building 820. Therefore, the entire building is considered to be a single fire area. Potential fire hazards in other areas of Building 820 which could affect the operations of the ATF are discussed in the appropriate sections below.

1.2 Windstorm Damage Potential

Due to the substantial metal panel construction, the windstorm damage potential at this facility is considered to be very slight.

2. Occupancy and Associated Fire Hazards

The existing and proposed occupancy of the ATF areas of Building 820 are considered to be industrial type operations. The ATF area is occupied by accelerator equipment, laser equipment,

FPA/FHA, ATF area of Bldg. 820, page 3

and associated experiment equipment. The accelerator equipment includes an electron gun, a linac, a transport line, and related equipment enclosed in concrete shielding walls. The major laser equipment includes a YAG laser in the clean room, a CO_2 laser, and a Terawatt laser by the north end of the accelerator. The Experiment Hall area of the ATF is occupied by beamlines and optical equipment associated with experiment operations. The remainder of the ATF areas of the building are occupied by various electrical, electronic, and mechanical equipment to provide for operation and control of the Accelerator and experiment equipment. There is also a mechanical equipment room, a machine shop room, and technicians space in separate rooms in the ATF area of Building 820. Combustible loading within the ATF areas of Bldg. 820 is light.

Automatic sprinkler protection is provided throughout the FEL Room, the CO_2 Laser Room, the north end of the Terawatt Laser Room, the Experiment Hall and vestibule, and the mezzanine area which houses the power supplies for the ATF. The two office trailers affiliated with the ATF also have automatic sprinkler protection. Other areas of Bldg. 820 do not have automatic sprinkler protection (see Recommendation FHA97-820-1). Attachment A and Attachment B show the areas currently provided with automatic sprinkler protection.

The CO2 laser, the Terawatt Laser, and the YAG laser are classified as Class 4 laser systems. Class 4 lasers are considered to be beam ignition hazards. To the extent possible, these laser installations and uses should comply with the recommended practices in NFPA 115, Laser Fire Protection. N. Gmur, the ES&H Coordinator and C. Weilandics, the Laboratory Laser Safety Officer, are in receipt of a copy of NFPA 115 (see Recommendation FHA97-820-2).

The scope of NFPA 318, Protection of Clean Rooms, is for semiconductor facilities containing clean rooms. The clean room in Bldg. 820 is not intended for semiconductor production and therefore was not designed to the requirements of NFPA 318. The clean room in Bldg. 820 was designed as a structure containing high value electronic equipment. The existing smoke detection within the clean room is adequate for the loss potential that exists within the room (less than one million dollars).

The clean room was specified to be constructed of a Class A building material. However, a Class C wall panel was used in the actual construction. To mitigate the hazards associated with this combustible construction, a clean agent automatic fire extinguishing system such as FM200 or Inergen is being recommended for the interior portions of the clean room (see Recommendation FHA97-820-4). In addition, to minimize the exposure of the Yag Laser Room and Laser Lab Room from an external fire, it is being recommended that the exterior surfaces of this combustible enclosure be covered with a fire rated barrier such as gypsum wallboard or by a noncombustible material such as sheet metal (see Recommendation FHA97-820-5).

Providing protection for the clean room as recommended above will reduce the probability of a large loss occurrence in Bldg. 820, but would not fully eliminate the potential for a large loss due to the exposure to the clean room and other areas of the ATF from unprotected areas of Bldg. 820. With the exception of the areas recommended to be protected by a clean agent fire suppression system, sprinkler protection in the unprotected areas of Bldg. 820 is warranted to reduce this exposure (see Recommendation FHA97-820-1).

The remainder of Bldg. 820 not occupied by the ATF is used by DAS as experiment lab space and by RHIC for work associated with cryogenic magnet production. The combustible loading in these areas of Bldg. 820 are considered to be light to moderate. Automatic sprinkler protection is not provided in these areas (see Recommendation FHA97-820-1). Automatic fire detection is provided in areas not protected by automatic sprinkler protection.

FPA/FHA, ATF area of Bldg. 820, page 4

2.1 Critical Process Equipment

By DOE standards, critical process equipment is considered to be equipment which, if lost or damaged in a credible fire, could delay a significant component of a major program for a period in excess of 6 months.
By the above definition, the accelerator and the associated equipment in the ATF areas of Building 820 are not considered to be critical process equipment.

2.2 Special Occupancies

Special occupancies include electronic data processing and vital/important records. The special occupancies of the ATF areas of Building 820 are expanded upon in sections 2.2.1 and 2.2.2, below.

2.2.1 Electronic Data Processing

The control equipment associated with the operation of the Accelerator at the ATF is located in a control room of substantial concrete block construction. Due to unrated penetrations, the walls of the control room are not considered to be fire rated. This arrangement is acceptable since the control room equipment is not considered to be essential as defined by DOE/EP-0108, Standard for Fire Protection of DOE Electronic Computer/Data Processing Systems. Smoke detection is provided in the control room.

2.2.2 Vital and Important Records Storage

Vital records are those records which are essential to the mission of an important program and which, if lost, could not be reproduced or obtained elsewhere. Important records are those records possessing a high value to the mission of an important program but which, if lost, could be reproduced or reconstructed with difficulty or extra expense.

Based on the above definition, there are no vital or important records associated with this program.

2.3 Unique Fire Hazards

Unique fire hazards include; modular buildings, trailers, cooling towers, flammable liquid & gas storage, cable trays, housekeeping in vital areas, and highly combustible building materials. The unique fire hazards of Building 820 are expanded upon in sections 2.3.1 through 2.3.7, below.

2.3.1 Modular Buildings

There is one modular building attached directly to Building 820. The modular building is remote in relation to the ATF and therefore does not present a direct exposure to the ATF.

2.3.2 Trailers

There are two trailers located 15 ft. west of the ATF area of Building 820. These trailers have a moderate amount of combustible loading and are considered to be an exposure hazard to the ATF areas of Building 820 (see section 6 for details). These two trailers are provided with automatic sprinkler protection. There is also a trailer at the north end of Building 820 which is attached directly to the building. This trailer has a moderate amount of combustible loading but its location is remote in relation to the ATF and therefore does not present a direct exposure to the ATF. This trailer is currently protected by an automatic Halon fire extinguishing system.

2.3.3 Cooling Towers

There are no cooling towers associated with the ATF area of Building 820. There is a large pad mounted chiller located approximately 5 ft. south of Bldg. 820. The chiller is constructed of noncombustible materials.

2.3.4 Flammable Liquid & Gas Storage

The amount of flammable liquids stored in the ATF area of Building 820 and that which exists in other areas of the building is minimal. Storage is generally restricted to a safety cabinet. Incidental use and storage outside of the flammable liquid storage cabinet does not exceed the quantities allowed by NFPA 30, Flammable and Combustible Liquids Code.

There is a Klystron/modulator system located in the ATF area of Building 820. The system contains approximately 150 gallons of a Class IIIB (FP > 300 deg. F.) combustible oil coolant similar to transformer oil. The system is provided with secondary containment. The oil coolant in the Klystron is considered not to contain PCBs. The oil was changed out several years ago from a documented source of PCB free oil coolant. Analysis of the oil performed on 10/31/97 showed that the oil contained less than 50 ppm PCBs. There is no automatic sprinkler protection associated with this combustible liquid hazard (see Recommendation FHA97-820-1).

There is also a high voltage insulator system associated with the Terawatt laser. The insulator system will contain approximately 500 gallons of a Class IIIB (FP > 295 deg. F.) combustible oil coolant similar to transformer oil. The oil coolant in the Terawatt is PCB free. The insulator system is provided with secondary containment. There is no automatic sprinkler protection associated with this hazard (see Recommendation FHA97-820-1). There are also two other devices associated with the Terawatt laser that contain oil. A D.C. power supply containing appx. 15 gallons of oil and a Pulse Forming Network (PFN) on the Terawatt laser which contains 25 gallons of oil. Automatic sprinkler protection is provided in the area of these two devices.

There is experiment use of flammable gas associated with the apparatus in the Experiment Hall area of the ATF. The flammable gas cylinders are located outside of the building and the system is hard piped to the experiment equipment. The flammable gas system is in compliance with the requirements in ES&H Standard 4.11.0, Installation of Flammable Gas Systems (Experiment and Temporary Systems).

2.3.5 Cable Trays

High voltage, low voltage, control, and signaling cables are generally segregated in accordance with NEC requirements throughout the ATF areas of Building 820. The cabling is located in conduits, raceways and cable trays. In most instances, the cables provided in the cable trays meet the IEEE 383 flammability test criteria. Automatic sprinkler protection is not provided in some of the areas of the ATF that contain cable trays (see Recommendation FHA97-820-1).

2.3.6 Housekeeping in Vital Areas

In general, housekeeping in Building 820 is adequate to minimize potential fire hazards. Some transient combustibles associated with the recent building renovations exist but it was indicated this material would be removed upon completion of the various upgrades.

FPA/FHA, ATF area of Bldg. 820, page 6

2.3.7 Highly Combustible Building Materials

No significant amounts of exposed polystyrene insulation or other highly combustible building materials are used in the construction or operations at Building 820. The clean room which houses the YAG laser system is constructed of a 3 in. thick polystyrene core wall system covered with a vinyl covered hardboard. The wall panels have a Class C flame spread rating and are considered to be of combustible construction.

3. Fire Protection/Suppression Features

Automatic sprinkler protection is provided in the North Addition to the ATF area of Bldg. 820 and throughout the mezzanine area of the ATF. This sprinkler system is designed to provide a minimum density of 0.15 gpm over the hydraulically most remote 2500 sq. ft. area. The water supply in the area of Building 820 is adequate to meet the required demand of this system including 250 gpm for hose streams.

Manual fire alarm pull stations are installed at all egress doors throughout Building 820. Partially supervised fire alarm bells are located throughout the facility. A duct smoke detector is provided on the air supply system which serves the CO_2 Laser Room, the Terawatt Laser Room, and the Experiment Hall areas of the ATF. Spot-type smoke detectors are located in the Laser Lab area, the Control Room, the power supply mezzanine, the Terawatt Laser Room, the CO_2 Laser Room, the Experimental Hall area, the FEL Room, and at the ceiling and below the raised floor in the Yag Laser Room.

Automatic heat detection is provided in the areas of the ATF not protected by automatic sprinklers or smoke detectors. Automatic sprinkler protection is not provided in the other areas of Bldg. 820 not occupied by the ATF (see Recommendation FHA97-820-1). Heat and/or smoke detectors are provided in these areas.

The building fire alarm system is arranged to annunciate: locally, at BNL Fire/Rescue Headquarters (Building 599), and BNL Police Headquarters (Building 50).

An adequate number of properly rated hand-held fire extinguishers are located throughout this facility.

The fire protection/suppression features of vital programs, high valued property, and essential safety class systems at Building 820 are expanded upon in sections 3.1 through 3.3, below.

3.1 Fire Protection of Vital Programs

The operation associated with this facility is not considered to be a vital program. Therefore, no special fire protection precautions, beyond those that are described above, are required for this facility.

3.2 Fire Protection of High Value Property

The major equipment and lasers associated with the ATF are considered to be high value property. Spot-type smoke detectors, a duct smoke detector, and sprinkler protection is provided in the area of the Experiment Hall, Terawatt Laser (partially), and CO_2 Laser. The Yag Laser Room is provided with spot-type smoke detectors. The power supplies on the mezzanine are protected with automatic sprinklers and spot-type smoke detectors. To provide further in-depth protection from a fire, a combination of automatic sprinkler protection and a clean agent fire

FPA/FHA, ATF area of Bldg. 820, page 7

extinguishing system is being recommended for areas that contain high value equipment (see Recommendation FHA97-820-1 and Recommendation FHA97-820-4). To reduce the facility user's concern of water damage to the high value equipment from an accidental sprinkler system discharge, a preaction sprinkler system should be used in the areas of the high valued equipment which will not be protected by a clean agent fire suppression system.

3.3 Protection of Essential Safety Class Systems

There are no essential safety class systems associated with this non-nuclear facility.

4. Fire Loss Potentials

Fire loss potentials are classified into three major categories; the maximum credible fire loss, the maximum possible fire loss, and the recovery potential. The loss potentials for Building 820 are expanded upon in sections 4.1 through 4.3, below.

4.1 Maximum Credible Fire Loss (MCFL)

The Maximum Credible Fire Loss (MCFL) for the ATF area of Building 820 is expected to be from $250,000 to over $1 million. Typical areas where a loss of this magnitude could be expected to occur include any of the three major laser installations, cable trays in the vicinity of the Accelerator and/or electron gun, electronic control equipment for the accelerator, and the oil filled Klystron/modulator system on the general floor area. Since the facility is not fully protected by automatic sprinkler protection, the maximum credible fire loss is estimated to be equal to the maximum possible fire loss as specified by DOE. Per DOE direction, manual firefighting operations can not be given credit in reducing the MCFL of an unsprinklered building. With the installation of an automatic sprinkler system throughout Bldg. 820, the maximum credible fire loss would be reduced to an acceptable level (under $250,000) (see Recommendation FHA97-820-1 and Recommendation FHA97-820-4).

4.2 Maximum Possible Fire Loss (MPFL)

The Maximum Possible Fire Loss (MPFL) for this facility is estimated to be the result of an uncontrolled fire in the general building area which would involve the coolant oil in the Klystron/modulator system or the insulator oil in the Terawatt laser system. Assuming a 25% loss and/or damage to the building and a 25% loss and/or damage to the building contents, including the accelerator and associated equipment and extensive damage to the associated cabling, a loss in excess of $1 million could be anticipated.

The MPFL for the ATF resulting from an uncontrolled fire originating in other areas of Building 820 is also estimated to be in excess of $1 million due to the continuity of combustibles and the smoke damage potential that could occur to the ATF equipment.

4.3 Recovery Potential

Due to the lack of fire protection, a credible fire in Building 820 could result in a shutdown of the ATF or a major component of the ATF for an excessive period of time (greater than 6 months).

5. Security Considerations Related to Fire Protection

There are no security considerations which relate to fire protection at this facility.

FPA/FHA, ATF area of Bldg. 820, page 8

6. Exposure Fire Potential

Exposure fire potential for the ATF area of Building 820 is limited to the possible exposure from the non-ATF areas of Building 820, two portable trailers west of the building, and a 1500 kVA transformer yard also located west of the facility. The space separations and other relevant factors of these exposures are discussed below. There are no additional fire exposures beyond those noted above.

There is a 15 foot separation between Building 820 and the two trailers to the west of the building. The trailers are fully sprinklered metal panel buildings with light combustible loading. Based on this information, the separation distance between Bldg. 820 and the trailers complies with the requirements in DOE-STD-1088-95, Fire Protection for Relocatable Structures and are not considered to be exposure hazards to Building 820.

Two oil filled transformers, rated at 2000 kVA and a 500 kVA respectively, are located more that 25 feet west of Building 820. The transformers are provided with adequate containment curbing. Based on Factory Mutual Data Sheet 5-4, the transformers are not considered an exposure hazard to Building 820.

The non-ATF areas of Bldg. 820 are considered to be a direct exposure to the ATF operations due to the lack of fire protection in most areas of the building (see Recommendation FHA97-820-1).

7. Environmental Impact due to a Fire (Including Water Runoff)

Toxic, biological, and radiation incidents resulting from a fire, including water runoff, could have an impact on the environment. The potential for these incidents occurring in the ATF areas of Building 820 are expanded upon in sections 7.1 through 7.3, below.

7.1 Toxic Incident

There are no known materials in the ATF areas of Building 820 that, if involved in a fire, would result in a significant quantity of toxic material being created and released.

7.2 Biological Incident

Due to the lack of biological matter at this facility, an incident of this type is unforeseeable.

7.3 Radiation Incident

No radioactive materials are used or stored in the ATF areas of Building 820. By the nature of the operations of the accelerator, various pieces of equipment can be expected to become activated. This activation is not expected to pose a significant environmental impact in the event of a fire.

8. Prefire and Emergency Planning

The BNL Fire Department maintains an adequate prefire plan book for this facility. A local emergency plan is maintained by the NSLS department.

8.1 Fire Apparatus Accessibility

Fire apparatus accessibility is adequate at this facility.

FPA/FHA, ATF area of Bldg. 820, page 9

9. Life Safety Considerations

Major life safety considerations for this industrial facility include the following components; means of egress components and capacity, number and arrangement of the means of egress, travel distances to exits, discharge from the exits, and emergency lighting and marking of the means of egress.

At Building 820, most of the above components are in accordance with the requirements of NFPA 101-94, The Life Safety Code. For further details, see the Life Safety Code analysis for this facility dated October 29, 1997 and updated February 3, 1999.

FPA/FHA, ATF area of Bldg. 820, page 10

Appendix A

Blind Recommendations

This appendix provides documentation for recommendations which are in the best interest of fire prevention but for which corrective action is not considered to be cost beneficial.

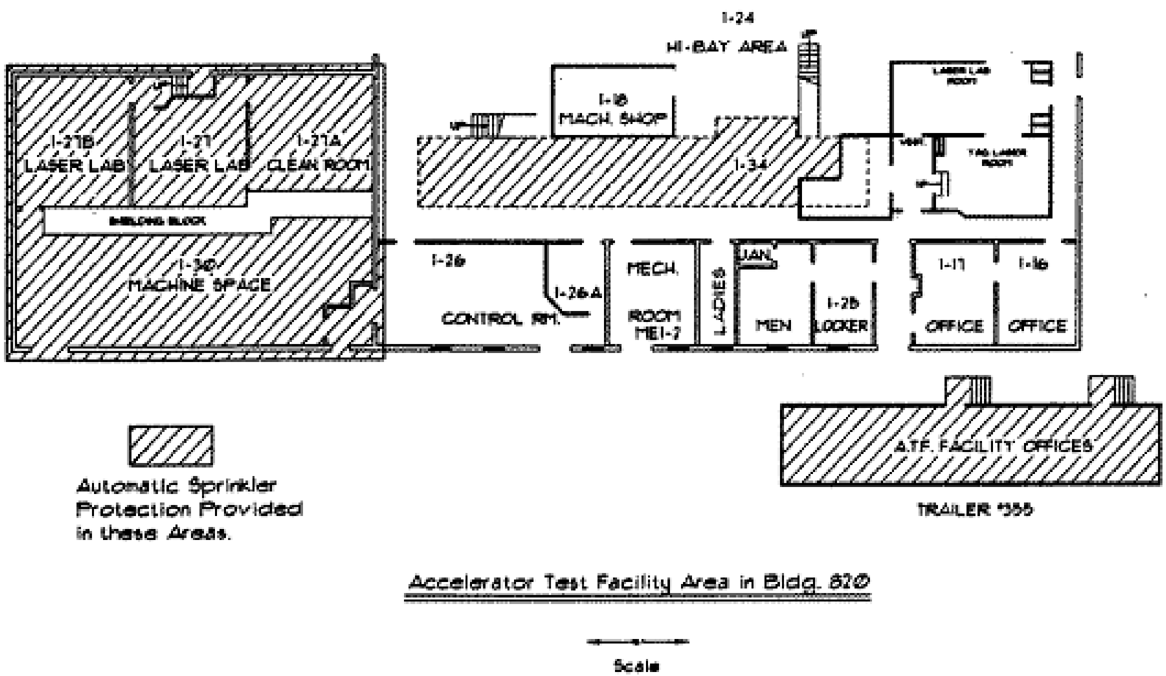
There are no blind recommendations as a result of this survey.

Appendix II (Cont.)

FPA/FHA, ATF area of Bldg. 820, page 11

Attachment A

Accelerator Test Facility Layout



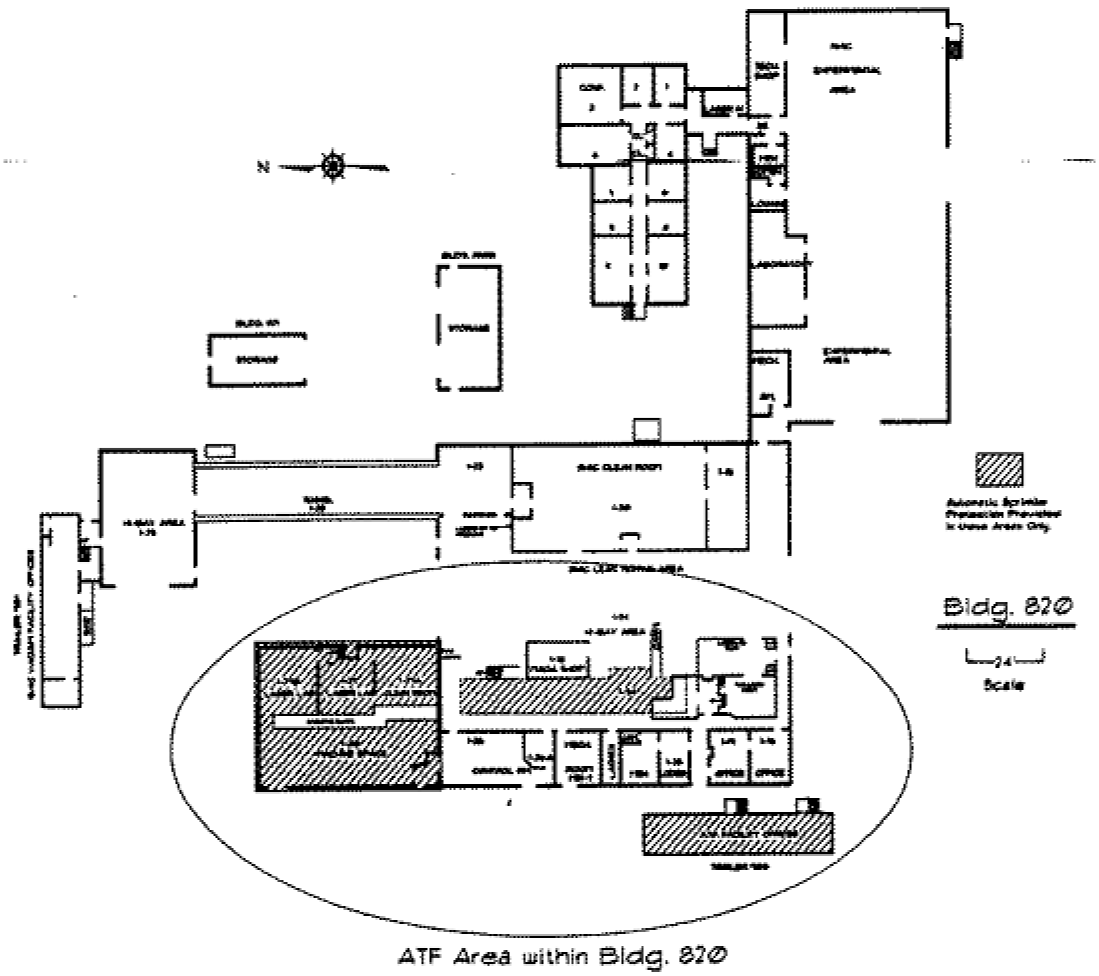
Accelerator Test Facility Area in Bldg. 820

Appendix II (Cont.)

FPA/FHA, ATF area of Bldg. 820, page 12

Attachment B

Building 820 Layout



Appendix III

Department of Energy
Brookhaven Area Office
53 Bell Avenue
Upton, New York 11973

November 24, 1989

U. S. Environmental Protection Agency
ATTN: Alan Feldman, Ph.D.
Director, Air & Waste Management Division
26 Federal Plaza
New York, New York 10278

Dear Dr. Feldman:

SUBJECT: STARTUP OF THE ACCELERATOR TEST FACILITY (ATF)

The Brookhaven Area Office of the Department of Energy wishes to notify EPA Region II that the Accelerator Test Facility commenced operation on November 1, 1989. This notification is provided to comply with Approval Condition III of the ATF NESHAPs Permit No. BNL-589-01 which requires notification to EPA of facility startup. As stated in prior correspondence, the ATF is operating in a test mode at energies on the order of 5 Mev. Operation of the facility at full design energies of 100 Mev is still several months in the future and will occur only after testing and beam reconfiguration at intermediate energies. Generation on any airborne activity is unlikely prior to 1990.

Sincerely,

Jerry L. Bellows
Area Manager

cc: K. Batchelor, BNL
W. Casey, BNL
M. Davis, BNL
M. Goldman, BNL
R. Miltenberger, BNL
J. Naidu, BNL
G. Penny, BHO
B. Royce, BNL
J. P. Kennedy, ESHD, CH

Appendix III (Cont.)

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

(516) 282 3711
FTS 666

Office of the Director

September 26, 1991

Ms. Jane L. Monhart
Acting Area Manager
U.S. Department of Energy
Brookhaven National Laboratory
Upton, New York 11973

Dear Ms. Monhart:

SUBJECT: START-UP OF ACCELERATOR TEST FACILITY (ATF) AT 100 MeV AND COMPLIANCE WITH NOTICE OF OPERATION REQUIREMENTS IN 40 CFR 61

According to the conditions listed in the EPA approval to construct ATF (NESHAPs Approval Number BNL-589-01), EPA requires notification of the facility start-up date within 30 days of the anticipated date of operation. The facility has informed us that operations are expected to commence at an increased energy of 100 MeV within the next 30 days (as of September 25, 1991). The EPA Region II should be notified of this. The notification should be sent to:

U.S. Environmental Protection Agency
Director, Air & Waste Management Division
26 Federal Plaza
New York, New York 10278

Attention: Florie Caporuscio, Ph.D.

Sincerely,

M S Davis

Gerald C. Kinne
Associate Director

GS:blc
cc: K. Batchelor
W. Casey
M. Davis
H. Kahnhauser
R. Miltenberger

Department of Energy
Brookhaven Area Office
Building 464
P.O. Box 5000
Upton, New York 11973

January 24, 1995

Dr. M. S. Davis
Associated Universities, Inc.
Brookhaven National Laboratory
Upton, New York 11973

Dear Dr. Davis:

SUBJECT: OPERATION OF THE ACCELERATOR TEST FACILITY (ATF) UP TO 120 MEV

The Brookhaven Area Office (BHO), Operations and Safety Management Division (OSMD), has reviewed the BNL Operational Readiness Review (ORR) of the ATF, the ATF's action plan and response, and the ORR's final concurrence.

BHO has subsequently conducted a walkthrough of the ATF that covered the equipment, accelerator, experimental, and control areas and included discussions with ATF staff on procedures, training, and system readiness for operation up to 120 MeV.

BHO found the facility to be in good order and in a state of readiness. BHO recognizes the good work done by the ATF and S&EP staffs to improve ATF practices and documentation with regard to safety and operations. Accordingly, BHO concurs with BNL's authorization to operate the ATF up to an energy of 120 MeV.

BHO fully expects that the ATF and S&EP staffs will continue to maintain the progress that has been demonstrated with respect to safety at the ATF. If you have any questions on this matter, please contact Pepin Carolan of my staff at extension 5966.

Sincerely,

Carson L. Nealy
Area Manager

cc: W. R. Casey, BNL
I. Ben-Zvi, BNL

Appendix IV

Authorization for Work on ATF Accelerator Safety Systems

This section to be completed by Requesting Personnel

Date: ______________________________

Person(s) Requesting Work Authorization: ______________________________

Systems Affected: ☐ Gun ☐ H-line/tunnel ☐ Other ______________________________

Date(s) work will be in progress: ______________________________

Person(s) Doing Work: ______________________________

Description of Work: ______________________________

____

____

This section to be completed by Safety Personnel

Required Safeguard: ☐ LOTO modulators ☐ LOTO Dipole ________ ☐ Other __________

____

Required Conditions or Restrictions on Work: ______________________________

____

☐ Shielding to be Replaced to Identical Configuration
☐ ESH Officer to Visually Inspect & Document Upon Completion
☐ Related Work Permit # ______________________________

☐ Check Here if Changes Are Required in Shielding Configuration ____________________

☐ Check Here if Review Required by Physics ES&H Cmte or Interlock Group ____________

Reviewed By (RCD/PESHC): ______________________________ Date: __________

Safeguard Placed By: ______________________________ Time/Date: __________

Authorization Released By (ATF ESH): ______________________________ Date: __________

Return to Service or Close Out By: ______________________________ Date: __________

☐ Check Here if Radiation Survey Required (List Beam Conditions & Other Requirements): ___

____

Survey By: ______________________________ Date: __________

Physics Document PO-ATF-SSA 1 (01/30/04) Authorization number ____________

Appendix V

Revision Review Log

UNREVIEWED SAFETY ISSUE No. 1

Radionuclide Production in Soil From 60 MeV Electrons at the Accelerator Test Facility, Building 820

Date: February 15, 2002

Note: This report will be appended to the Accelerator Test Facility Safety Assessment Document as a USI.

W. R. Casey	2/22/02
Signature of Preparer	Date
Stephen V. Musolino	2/22/02
Signature of Reviewer	Date
	2/22/02
Signature of Reviewer	Date
Henry F. Kahnhauser	2/24/02
Signature of Reviewer	Date
Ilan Ben-Zvi	2/28/02
Signature of Head of ATF	Date

Appendix V (Cont.)

Radionuclide Production in Soil From 60 MeV Electrons at ATF

Introduction

A reorientation of the ATF beam line 1 resulted in a 90° bend toward the floor and the creation of a new stop to terminate the beam in. Because this orientation results in the forward directed beam pointed to the soil beneath the building, it was judged to be worthwhile to evaluate the potential for tritium and Na-22 production in soil. In a previous note from Hu to Gmur dated 1/10/02, the tritium production rate from neutron capture in naturally occurring deuterium was evaluated. In this note, we will also evaluate tritium and sodium-22 production from high energy neutron spallation.

Background

Activation in soil from the operation of accelerators has become an important issue at BNL. Considerable effort has been made at RHIC, BLIP, and the AGS to provide controls to minimize the production and dispersal of tritium in the soil, and questions are often raised about the steps that accelerators in the NSLS Complex have taken to prevent tritium production from its operations. (Note: tritium analyses were conducted of cooling water samples in 1997 and 2001; all values were below MDL.) It should be noted that there are several reasons why the potential for production of radionuclides in soil at the NSLS is very much lower than at our sister facilities such as AGS and RHIC. These factors can be used to qualitatively estimate the differences in radionuclide production in soil between these facilities.

One important reason is that the NSLS accelerates electrons rather than protons. The ability of electrons compared to protons to create non-elastic reactions in target materials is inherently smaller by a factor of about 100. Non-elastic reactions are required if spallation products such as tritium are to be produced in significant quantities. Secondly, the NSLS operates a much lower power levels than the proton facilities at BNL. For example, the x-ray ring at NSLS operates with a circulating beam of ~ 1×10^{12} electrons at 2.8 GeV produced once every 12 hours. The AGS operates with a 30 GeV beam of greater than 1×10^{13} protons produced every few seconds. Therefore, the AGS has ~10^6 greater beam power than the X-ray ring averaged over a 12 hour operating period. Combing the two factors, overall, the x-ray ring has ~ 10^{-8} less capability to produce residual radiation during a normal 12 hour operating period than the AGS does. Other NSLS accelerators such as SDL and ATF operate with higher beam power (but lower energies) than the storage ring, but still operate at several orders of magnitude less power than the AGS.

It is also possible to quantitatively estimate the level of induced tritium produced in the soil from electron beam interactions in a target. High energy electrons interacting in matter lose their energy primarily through production of bremsstrahlung radiation directed in the forward direction. The bremsstrahlung photons lose energy primarily

Appendix V (Cont.)

through interaction with atomic electrons, but some fraction of the photons will produce non-elastic collisions in a nucleus, thereby releasing high energy neutrons which can cause non-elastic interactions in other nuclei.

These high energy neutrons can produce radionuclides through spallation of the target nucleus. These production rates can be estimated through the following methodology.

In the ATF stop, the electron beam strikes a faraday cup and generates a bremsstrahlung beam that is intercepted by a 2" thick lead stop. In addition, there is a 12" concrete floor above the soil. Most of the neutrons will be created in the lead which represents a thick target of about 9 radiation lengths. The attached figure 1 provides an estimate of the high energy neutron (E > 25 MeV) production rates at 90^o. Rohrig in attachment #2 (Ref. 1) has estimated that the dose at 0^o is about four times as great as the rate at 90^o. Using the value from attachment 1 at 100 MeV

$$H_{HEN} = 4 \text{ x } 0.1 = 0.4 \text{ Sv/hr-KW at 1 m}$$

The total power of the electron beam is 60 MeV x 1.5 nA = 9×10^{-2} watts. The neutron fluence to dose equivalent for HEN = 4 n/cm^2-s per mRem/hr. Therefore, the HEN fluence Φ at 1 m from the lead is:

$$\Phi = 0.4 \text{ Sv/hr-KW x1 x} 10^5 \text{ mRem/Sv x } 9 \text{ x} 10^{-5} \text{ KW x 4 n/cm}^2\text{-s/mRem/hr} = 14.4 \text{ n/cm}^2\text{-s}$$

Neutrons created in the lead must penetrate through 12" of concrete before entering the soil. The attenuation length in concrete for neutrons in this energy range is 55 g/cm^2.

$$\Phi = 14.4 \text{ x } e^{-12'' \text{ x } 2.54 \text{ x } 2.35 / 55} = 3.9 \text{ n/cm}^2\text{-s at 1 m}$$

We assume the soil starts at approximately 1/2 m from the target. Correcting for geometry, the fluence at the beginning of the soil is:

$$\Phi = 4 \text{ x } 3.9 \text{ n/cm}^2\text{-s} = 15.7 \text{ n/cm}^2\text{-s}$$

The tritium production rate A can be calculated from:

$$A = N\sigma\Phi(1 - e^{-\lambda t})$$

The cross section σ for tritium production from spallation in oxygen and silicon is taken as 10 millibarns (mb) from attachment 3 from reference 2. The number of target atoms per gram in soil (SiO_2) with density 1.6 g/cc is N:

$$N = 6.02 \text{ x } 10^{23} \text{ molecules per gram-mole x 3 atoms/molecule} \div 60 \text{ g/ g-mole}$$

$$N = 3 \text{ x } 10^{22} \text{ atoms / g}$$

t is the irradiation time and the tritium decay constant $\lambda = 0.056 \text{ yr}^{-1}$.

Appendix V (Cont.)

Therefore the tritium production "A" rate in disintegrations per second per gram of soil from one year of full time operation is

$$A(1\ yr) = 3 \times 10^{22} \times 10 \times 10^{-27} \times 15.7 \times (1 - e^{-0.056 \times 1}) =$$

$$A(1\ yr) = 2.56 \times 10^{-4}\ d/s/g$$

The actual operating time for ATF in this mode is approximately 750 hours per year which reduces the production rate in the course of the year to

$$A(1\ yr) = 2.56 \times 10^{-4}\ d/s/g \times 8.56 \times 10^{-2} = 2.2 \times 10^{-5}\ d/s/g = 6 \times 10^{-4}\ pCi/g\ H^3 \text{ in soil}$$

The Accelerator Safety Subject Area provides a methodology for determining the acceptability of induced activity in soil. In the model, all the radioactivity produced in one year is assumed to be located within 1 attenuation length of entry into the soil. This amount of tritium is concentrated within the water in the soil and is then diluted by the average height of rainfall in a year. The computed concentration in the assumed leachate is compared to 5% of the drinking water standard. It should be noted that this is a hypothetical calculation to determine whether engineered rain caps are needed. The ATF beam stop is within a building and the activated soil is covered by the footprint of the building. The beamstop is located ~6 meters from an exterior building wall.

Using this methodology, the concentration in soil is:

$$C\ (soil) = 6 \times 10^{-4}\ pCi/g \times 1.6\ g/cc = 9.6 \times 10^{-4}\ pCi/cc$$

Using the factors for calculating soil water leachate, we get:

$$C\ (H^3 \text{ soil water leachate}) = 9.6 \times 10^{-4}\ pCi/cc \div 0.1 \div 55 = 1.74 \times 10^{-4}\ pCi/cc = 0.17\ pCi/l$$

The Subject Area establishes that calculated H^3 leachate values in excess of 1000 pCi/l would require further safeguards and monitoring. Therefore, no corrective actions are required for this level of tritium production.

The subject area also requires that Na^{22} production be calculated. Cross-sections for Na^{22} production were not available, so the measurement and calculations for H^3 and production from SLAC RP-2000-07 (Ref. 3) were used to estimate Na^{22} productions rates. That report estimates that

$$A_{Sat.}(Na^{22}) = 1/2\ A_{Sat.}(H^3)$$

Using the equations given above, $A_{Sat.}(H^3)$ can be calculated to be

$$A_{Sat.}(H^3) = 0.127\ pCi/g$$

Therefore ,

$$A_{Sat.}(Na^{22}) = 6.4 \times 10^{-2}\ pCi/g$$

Appendix V (Cont.)

We can then calculate the production in one year to be:

$$A_{1\ yr..}(Na^{22}) = 1.5 \times 10^{-2}\ pCi/g \text{ or}$$

$$A_{750\ hours}(Na^{22}) = 1.28 \times 10^{-3}\ pCi/g$$

Using the methodology described in the subject area for sodium, it can be calculated that the concentration in soil water leachate for Na^{22} is

$$C\ (Na^{22} \text{ soil water leachate}) = 2.8 \times 10^{-5}\ pCi/cc = 2.8 \times 10^{-2}\ pCi/l$$

which is considerably lower than the action level of 20 pCi/l.

Conclusion

Tritium and sodium-22 production in soil from operation of ATF beam line 1 in the new configuration does not require any additional engineering controls or monitoring.

References

1. Norman Rohrig - "Evaluation of Required Additional Shielding for Hypothetical Accidental Losses from the BNL National Light Source from an Upgraded X-ray Ring Injector - Feb. 3, 2002
2. W.R. Nelson, A. Fasso, R. Sit, and S.N. Witebsky - "Estimate of Tritium Production in Groundwater near SLC Beam Dumps" Feb. 1998; SLAC RP Note 98/2R
3. James Liu and Sayed Rokni - "Analytical Method in Estimating the Induced radioactivity in Soil around High energy Accelerators" Oct, 2000; SLAC RP Note 2000-07

Appendix V (Cont.)

Attachment 1

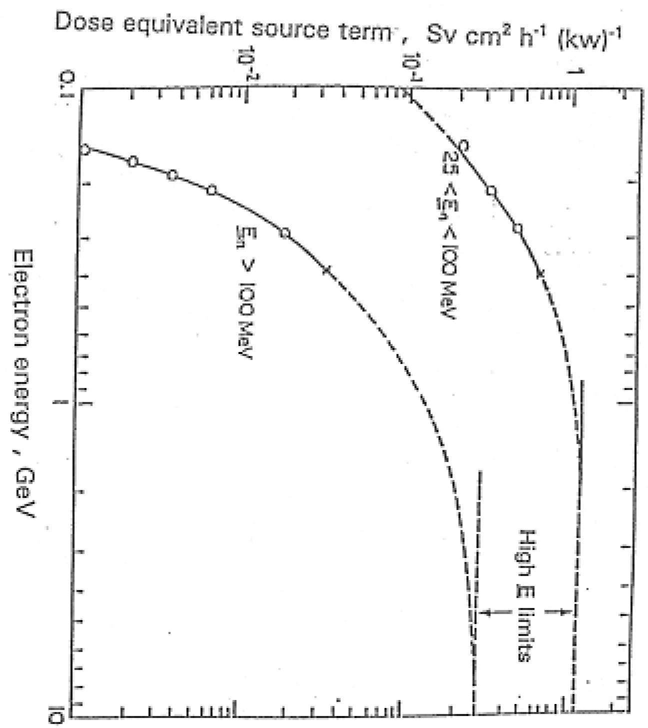


Fig. 4.21. Effective source terms for a thick copper target for neutrons of energy 25 to 100 MeV and for neutrons of energy greater than 100 MeV as a function of electron energy.

Appendix V (Cont.)

Attachment 2

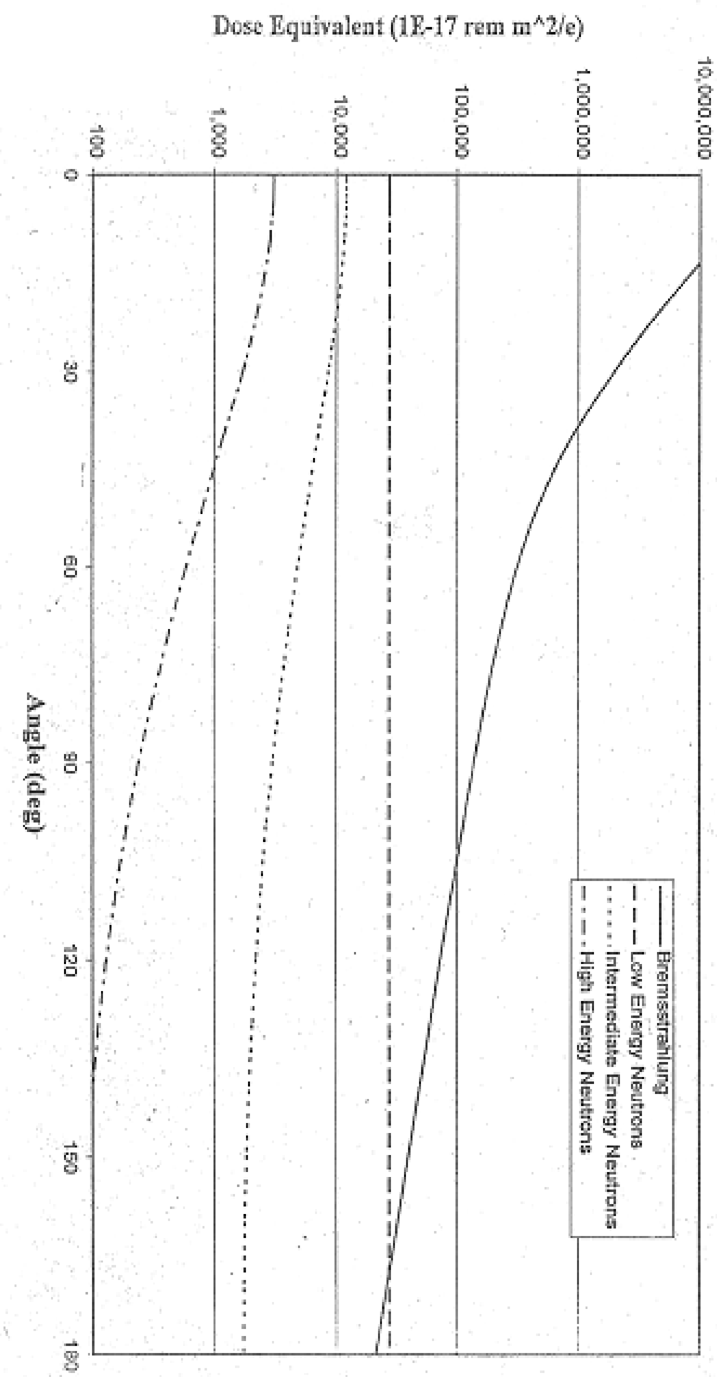


Figure 2: Unshielded Radiation Source Terms

lateral to the dump calculates to be

$$A_\infty = (2.7 \times 10^{-10}\ {}^3\text{H atoms/ml/e}) \times (6.25 \times 10^{12}\ \text{e/s}) \times (1\ \text{d}/{}^3\text{H atom}) \times \left(\frac{10^6 \mu\text{Ci}}{3.7 \times 10^{10}\ \text{d/s}}\right) = 4.6 \times 10^{-2}\ (\pm 34\%)\ \mu\text{Ci/ml}$$

for a 50 kW beam running continuously.

An Independent Check on FLUKA Using SHIELD11

SHIELD11[7] is a fast and easy to use code for performing shielding analysis around a high-energy electron accelerator. It makes use of simple analytic expressions for the production and attenuation of photons and neutrons by electron beams striking thick targets, such as dumps, stoppers, collimators, and other beam devices. The formulae in SHIELD11 are based on the extrapolation (*i.e.*, scaling) of experimental data using rather simple physics ideas and the code has been used at SLAC for many years with great success.

Using the dimensions of the dump and vault provided in Figure 2, the high-energy neutron dose-equivalent rate, at a distance of 42-inches from and 90° to the beam direction, is estimated by SHIELD11 to be 7.4 rem/h/kW. With the conversion factor of 1.0×10^{-7} rem/n cm^{-2} recommended by Jenkins[12] the fluence rate calculates to be 1.0×10^6 n/cm^{2}s opposite the dump (point P_1 in Figure 2) for 50 kW of beam running continuously.

Now, cross sections for the formation of tritium by high-energy hadrons have been measured for various materials (*e.g.*, see Noguchi *et al.*[13]) and the results are summarized in Figure 5.

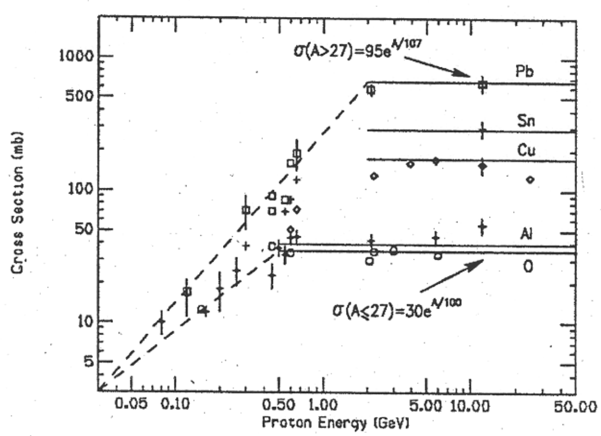


Fig. 5 Tritium formation cross sections as a function of proton energy.